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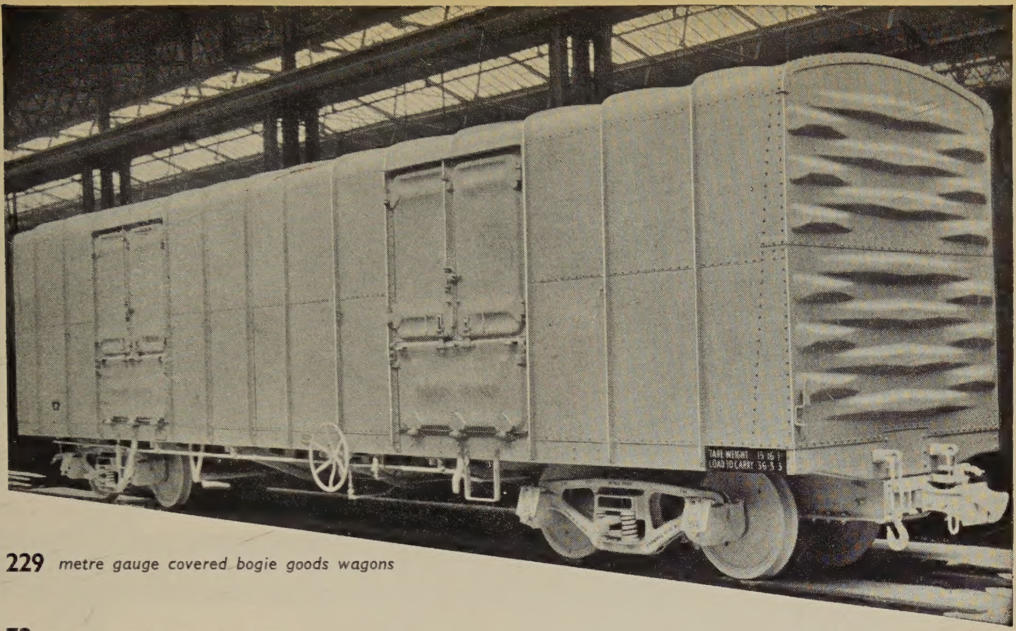

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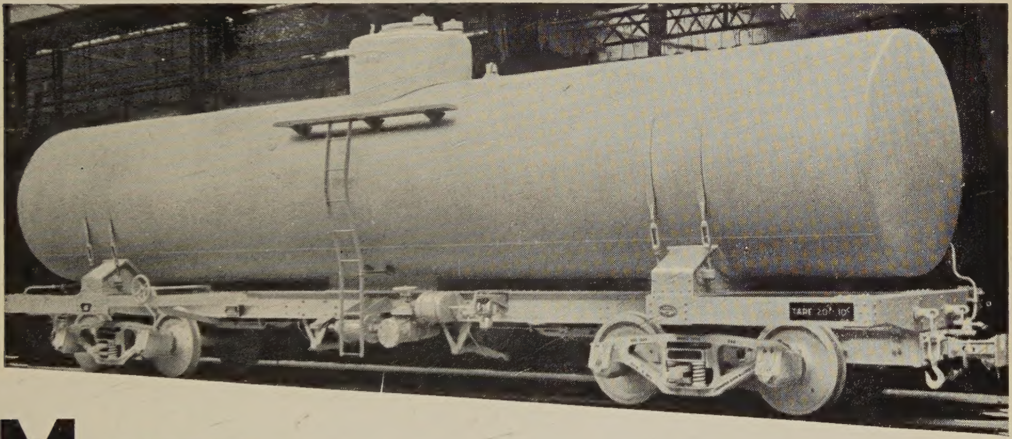

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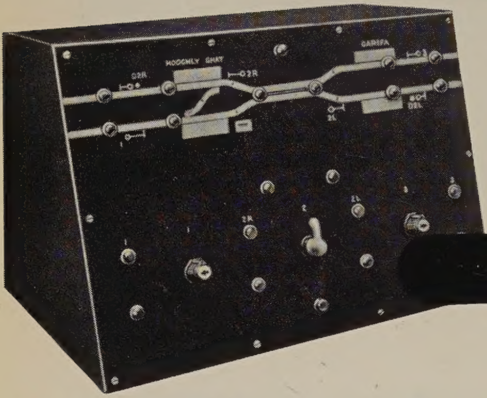

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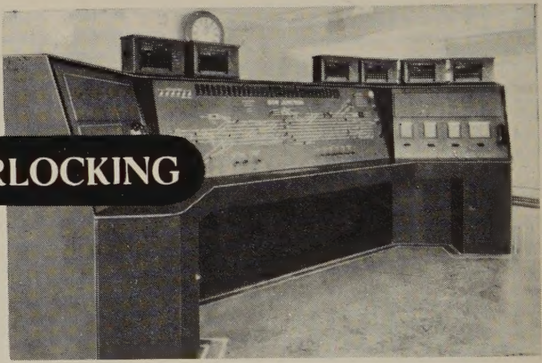

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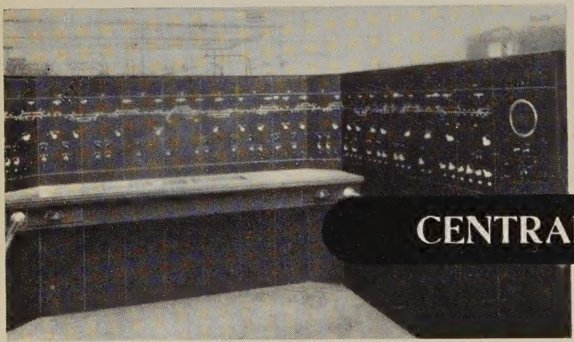

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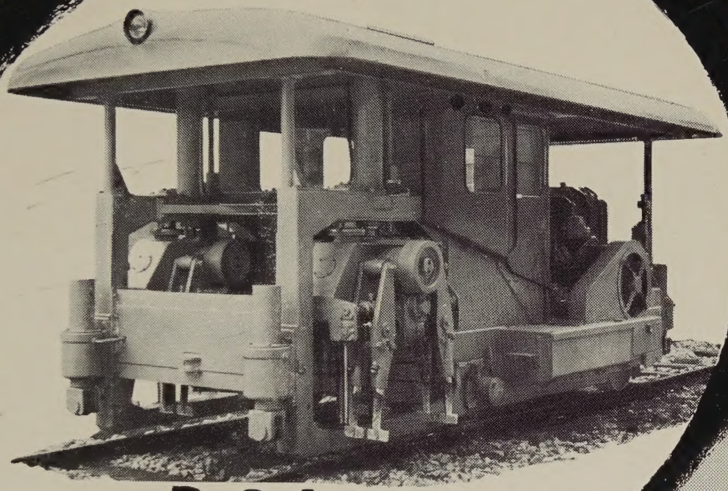

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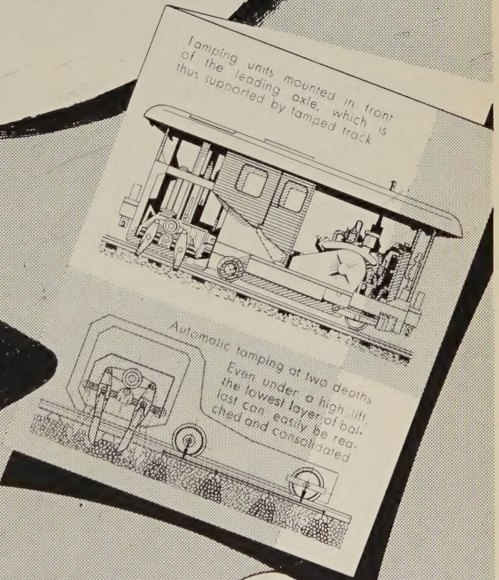

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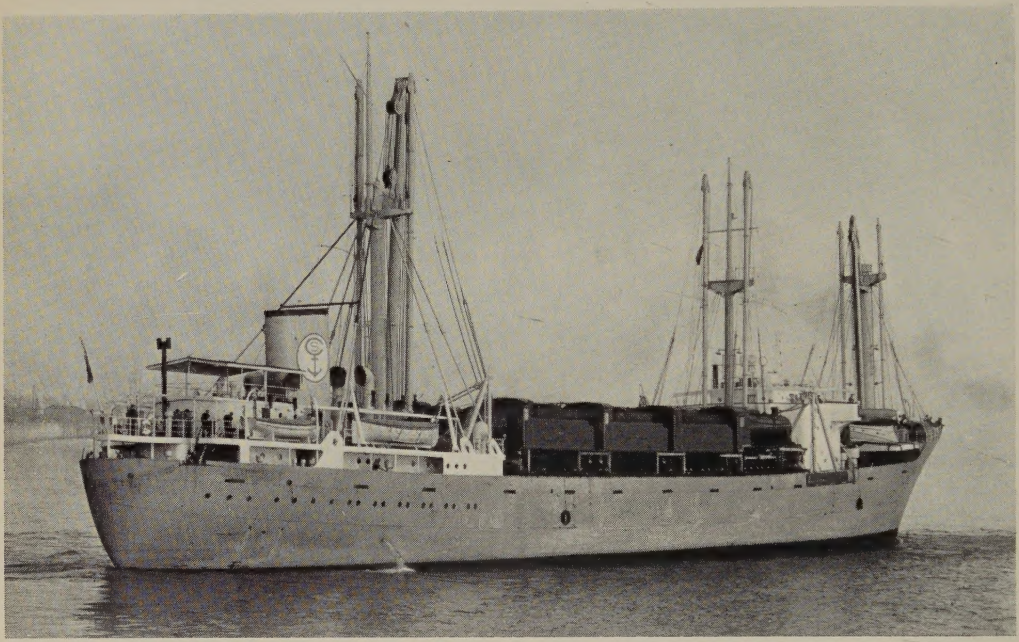

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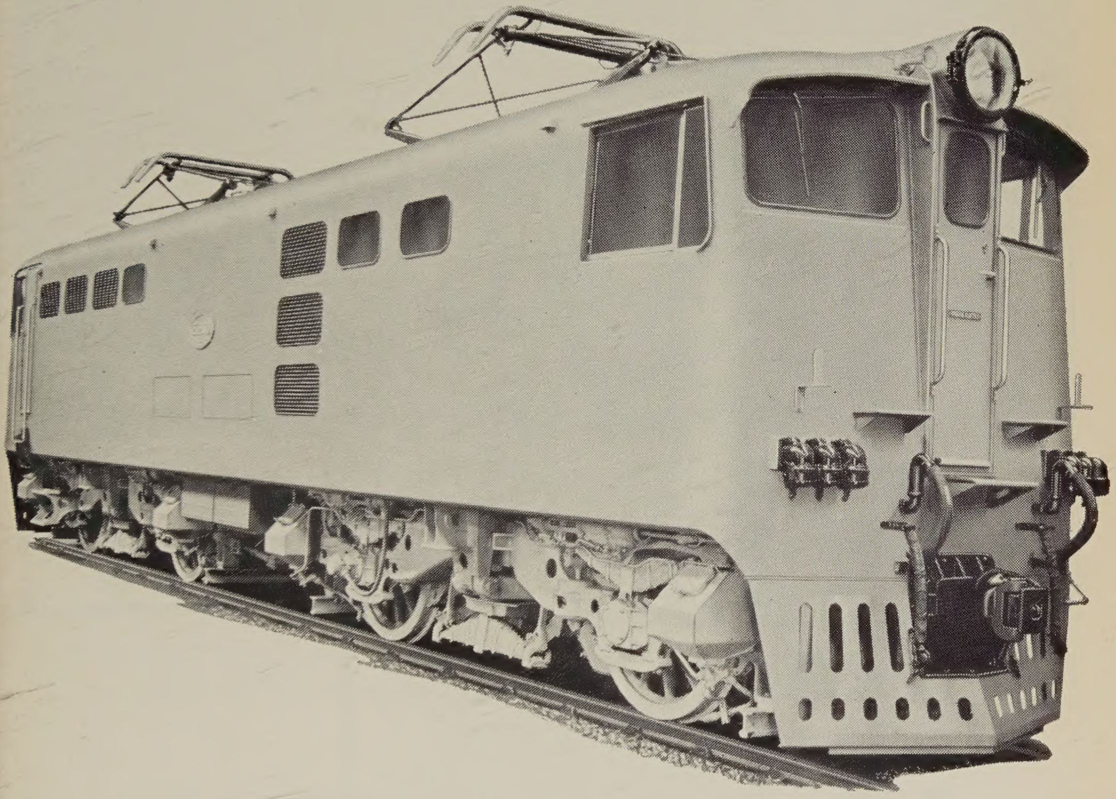

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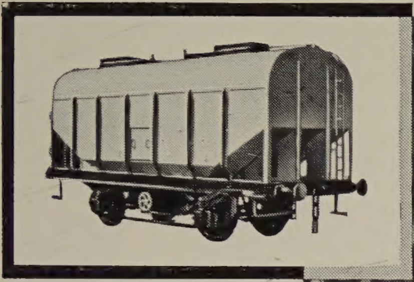

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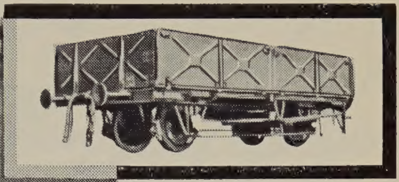

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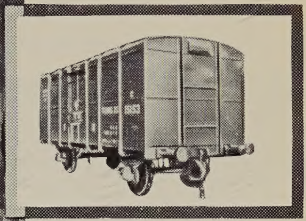

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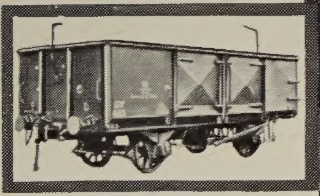

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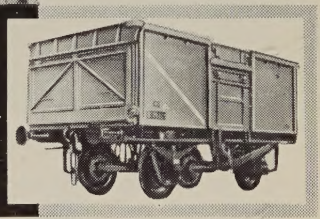

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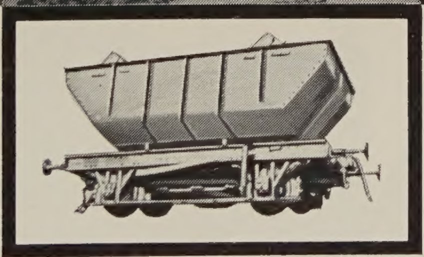

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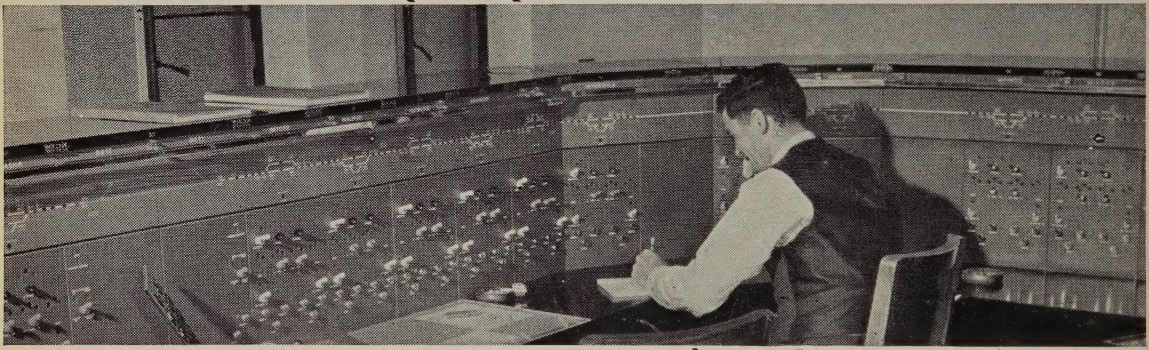

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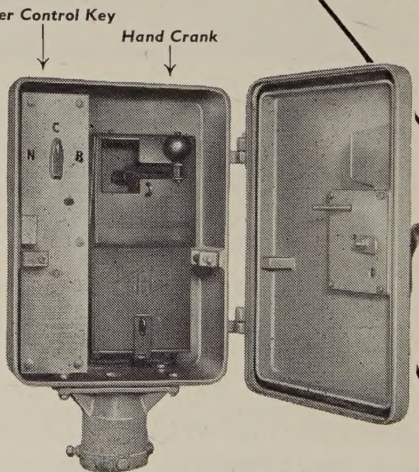

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# MONTHLY BULLETIN
OF THE
# INTERNATIONAL RAILWAY CONGRESS ASSOCIATION
(ENGLISH EDITION)

**PUBLISHING and EDITORIAL OFFICES: 19, RUE DU BEAU-SITE, BRUSSELS**

**Yearly subscription for 1957 :**
**Belgium . . . . . . . . . . . 700 Belgian Francs**
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**Price of this single copy : 80 Belgian Francs (not including postage).**

**Subscriptions and orders for single copies (January 1931 and later editions) to be addressed to the General Secretary, International Railway Congress Association, 19, rue du Beau-Site, Brussels (Belgium).**

Orders for copies previous to January 1931 should be addressed to Messrs. Weissenbruch & Co. Ltd., Printers, 49, rue du Poinçon, Brussels.

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Vol. XXXIV. — No. 2. February 1957.

BULLETIN
OF THE
INTERNATIONAL RAILWAY CONGRESS
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[ 656 .212 .5 ]

# Determining the marshalling times of wagons in marshalling yards,

by Dimitrije S. Živković,

Chef de Section et Conseiller de la Direction Générale des Chemins de fer Yougoslaves.

In railway operation considerable importance is attached to a figure known as « wagon round-trip time » ($\delta$).

By « wagon round-trip time » is meant the average time interval between two consecutive loading operations. As a very rough approximation, it may be assumed that the wagon round-trip time is the ratio of the rolling stock available ($n_v$) and the « output value » (L), i. e. the number of wagons per day loaded on the railway system or received loaded from adjacent railway systems.

Hence :

$$\delta = \frac{n_v}{L}$$

This relationship can be analysed in greater detail by applying either the « three-term equation » or the « five-term equation » for the wagon round-trip time.

The three-term equation is :

$$\delta = \frac{l}{V_k} + \frac{\phantom{l}}{E_d} \cdot t_{dA} + K_G \cdot t_G$$

where :

$l$ = distance in kilometres covered by the wagon between two consecutive loading operations;

$V_k$ = overall speed of the train between marshalling yards, in kilometres per hour;

$E_d$ = average distance between marshalling yards in kilometres;

$t_{dA}$ = average time, in hours, spent by wagons in the marshalling yards;

$K_G$ = a coefficient known as « local output coefficient », being the ratio of the total number of wagons loaded and unloaded on the system ($L_b$ and $L_e$, respectively), and the total output (L), i.e. :

$$K_G = \frac{L_b + L_e}{L}$$

$t_G$ = average time, in hours, required for the terminal handling (loading or unloading) of wagons.

The five-term equation runs as follows :

$$\delta = \frac{l}{V_t} + \frac{l}{V_k}(1 - \beta) + \frac{l}{E_{Tr}} \cdot t_{Tr} + \frac{l}{E_{Um}} \cdot t_{Um} + K_G \cdot t_G$$

where :

$V_t$ = the technical speed of trains between marshalling yards, in kilometres per hour, this being the ratio of the distance between the marshalling yards (E) in kilometres and the duration of the trip ($t_f$) in hours, not counting the stops of the train at intermediate stations :

$$V_t = \frac{E}{t_f} \text{ km.p.h.};$$

$\beta$ = speed coefficient, being the ratio $\frac{V_k}{V_t}$;

$E_{Tr}$ = average distance between marshalling yards, for through trains;

$E_{Um}$ = average distance between marshalling yards, for wagons of trains which are re-marshalled;

$t_{Tr}$ and

$t_{Um}$ = the corresponding average times spent by wagons in the marshalling yards.

The remaining symbols have the meaning already indicated.

It is well known that the average time spent by wagons at the marshalling yards ($t_{dA}$) has a certain bearing on the total round-trip time of the wagons and on the length of sidings required for the handling of the trains.

In the five-term equation for the wagon round-trip time, this time is sub-divided into :

*a*) the time required for the transit of wagons at the marshalling yards, $t_{Tr}$ and

*b*) the time required for the handling of wagons in the marshalling yards, $t_{Um}$.

$t_{dA}$ is equal to $t_{Um}$ if the work is not sufficiently organized, i. e. if no direct trains are formed which pass as block trains through several marshalling yards, but only short-distance trains conveying wagons from one marshalling yard to the next.

If direct trains are formed which run as block trains through a number of marshalling yards, the time $t_{dA}$ is split up into $t_{Tr}$ and $t_{Um}$. At the transit yards, however, one must have $t_{dA} < t_{Um}$.

The time required at the marshalling yards for the handling of the trains is composed of the following partial times :

(1) the time ($y_{Ans}$) needed for the marshalling of a sufficient number of wagons (*m*) required to form a train;

(2) the time ($t_z$) required for the technical composition, wagon checking, take-over and dispatch of a train.

The time spent at the marshalling yards by wagons of through trains comprises exclusively the time needed for the change of locomotive and relief of train staff.

It is therefore possible to show the breakdown of the time spent by wagons at marshalling yards in the way illustrated by figure 1.

The times $t_{Tr}$ and $t_z$ can be timed or laid down in the form of standards. The time required for the marshalling of wagons depends on the nature of the traffic and on the organisation of the work as we shall see later.

Let us assume that there are, on a line from A to D, the marshalling yards A, X, B and C, and the yard A is the focal point of a number of lines Y — A, Z — A, ... K — A (cf. fig. 2).

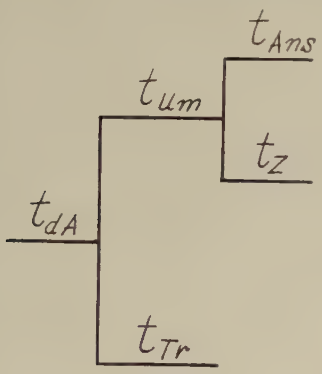

Fig. 1.

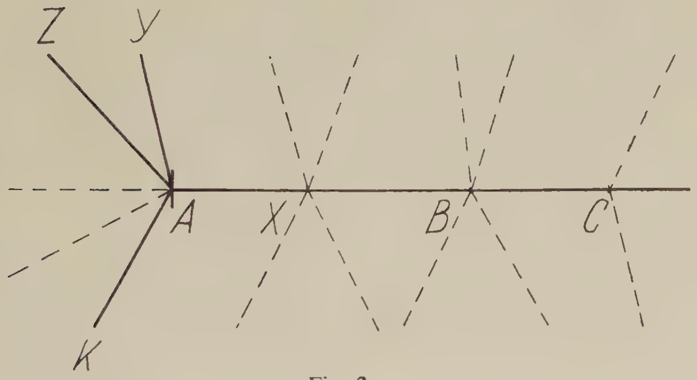

Fig. 2.

Let us also assume that there are batches of wagons, as shown in Table 1, for the section of a line from A to X and beyond X to C.

TABLE 1.

| to / from | X | B | C |
|---|---|---|---|
| A | $N_1$ | $N_2$ | $N_3$ |
| X | — | $N_4$ | $N_5$ |
| B | — | — | $N_6$ |
| $\Sigma$ | $N_1$ | $N_2 + N_4$ | $N_3 + N_5 + N_6$ |

These batches of wagons can be despatched in several different ways.

The first and simplest method which is always the first to be resorted to, is for yard A to assign to a single siding all the wagons concerned, arriving from all directions, i. e. Y, Z, ... K, and when the number of these wagons has become large enough to form a train, i. e. when $m$ wagons are assembled in that siding, to form a train destined for X. But as this train contains a mixture of wagons of batches $N_1$, $N_2$ and $N_3$, the train must be taken to a siding at X, partly in order to detach the $N_1$ wagons which continue in a different direction or leave station X in mixed trains, and partly in order to marshal in a single siding the wagons of batches $N_2$ and $N_3$ with those of batches $N_4$ and $N_5$ received from other directions so as to form a train of *m* wagons in the direction of B, etc. This method is graphically illustrated in the top part of figure 3.

The second method, illustrated in the central part of figure 3, assumes a combination according to which all $N_1$ and $N_2$ wagons coming from different directions are placed in one siding of yard A, and all $N_3$ wagons on another siding. In this way, two different types of direct trains are formed by the yard out of the unsorted wagons arriving there : trains with $N_1$ and $N_2$ wagons destined for X, and trains with $N_3$ wagons destined for C (direct trains passing through several marshalling yards without being re-marshalled).

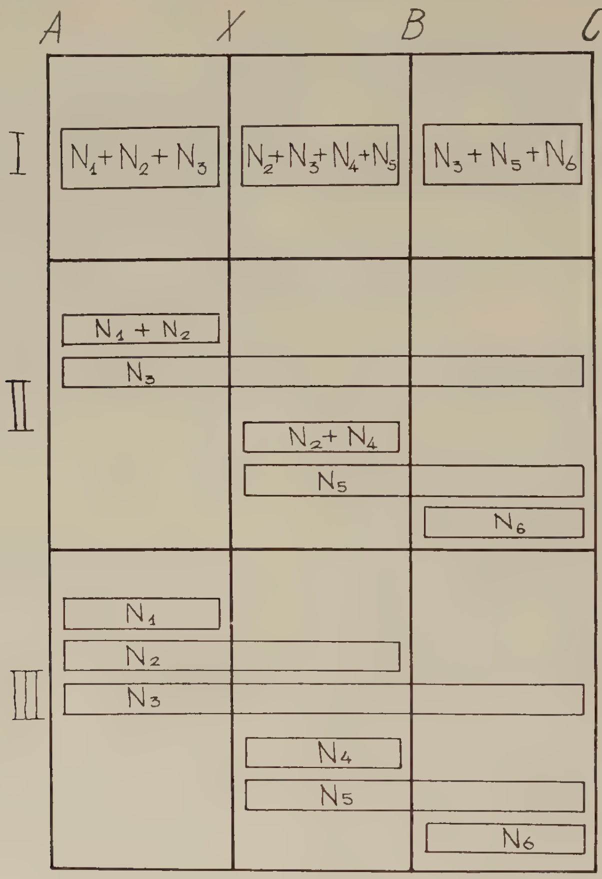

Fig. 3.

This combination necessitates an increase in the number of sidings at yard A as well as an increase in the average marshalling time of the wagons, as it is necessary for the yard to wait until *m*, $N_1$ and $N_2$ wagons are available to form a direct train destined for X, and *m* $N_3$ wagons to form a direct train destined for C.

On the other hand, this combination enables the $N_3$ batches to pass both X and B without being re-marshalled.

With the third method, illustrated in the bottom part of figure 3, the wagons coming from all directions are marshalled in three different sidings of yard A. It is obvious that the average marshalling time of the wagons will thus become even longer, as it is necessary to wait for *m* $N_1$ wagons to form a train for X, *m* $N_2$ wagons to form a train for B, and *m* $N_3$ wagons to form a train for C.

Apart from a further increase in the time required for the marshalling of the wagons at the yard, this method also calls for an increase in the number of sidings at yard A.

On the other hand, this method enables not only the $N_3$ batches but also the $N_2$ to pass through X without stopping.

This examination shows that any batching of wagons for individual destinations, and any formation of special direct trains to particular destinations calls for an increase in the number of sorting sidings at the yard concerned, and results in an increase in the average marshalling time. But this drawback is balanced by the fact that it is no longer necessary to re-marshal the wagons concerned at the marshalling yards en route.

As far as the wagon-round-trip is concerned, the most favourable method is the one which ultimately requires the minimum number of wagon hours incurred at the first yard as well as at the intermediate yards.

Let us now assume that the time required for the batching of the wagons at A, X and B is $t_{Ans}$ per wagon with the first method, 2 $t_{Ans}$ with the second method, and 3 $t_{Ans}$ with the third method. If the time required to form the train is $t_z$ in each case, and if the average time required for passing through a yard without re-marshalling is $t_{Tr}$ per wagon, the total number of wagon hours ($\Sigma T$) works out as follows :

With the first method :

$$\Sigma T_1 = (N_1 + 2\,N_2 + 3\,N_3) \cdot (t_{Ans} + t_z).$$

With the second method :

$$\Sigma T_2 = (N_1 + 2\,N_2 + N_3) \cdot (2\,t_{Ans} + t_z) + 2\,N_3 \cdot t_{Tr}.$$

With the third method :

$$\Sigma T_3 = (N_1 + N_2 + N_3) \cdot (3\,t_{Ans} + t_z) + (N_2 + 2\,N_3) \cdot t_{Tr}.$$

It must be remembered in this connection that, as far as the expenses are concerned, every hour spent on marshalling the wagons and forming the trains is equivalent to between 1.5 and 2 hours of wagons passing through without re-marshalling. In fact, during the marshalling and train forming operations, the wagons are being shunted. In other words, the train must be put into a siding after its arrival and must be reformed before its departure, whereas trains with wagons which pass through the yard without re-marshalling need not be shunted and do not, therefore, require the assistance of shunting locomotives.

The method which yields the minimum number of wagon hours ($\Sigma T$) can be determined most easily if the exact value of $t_{Ans}$ for each of the methods is known, taking into account not only the $N_1$, $N_2$ and $N_3$ wagons but also the $N_4$, $N_5$ and $N_6$ wagons.

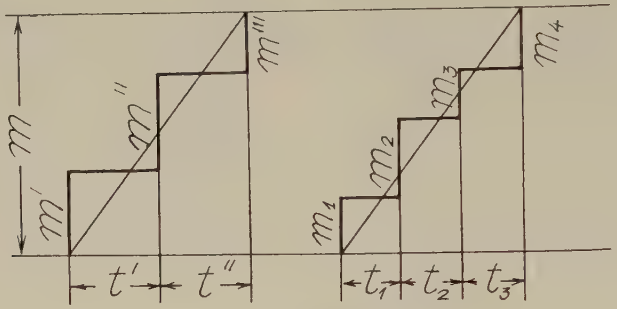

Fig. 4.

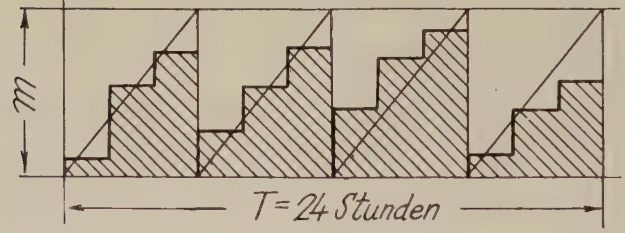

Fig. 5.
24 Stunden = 24 hours.

### Calculating the wagon marshalling times.

Two methods have been used in the past for the calculation of the wagon marshalling times.

*First method.* — Let us assume that m′ wagons have arrived with the first trains, another $m''$ wagons at the end of a period of time $t'$, and another $m'''$ wagons at the end of a further period of time $t''$ so that there are (cf. fig. 4) altogether $m = (m' + m'' + m''')$ wagons.

The loss in wagon round-trip time due to marshalling works out as follows :

— for the first train :

$$\Sigma T_1 = m' (t' + t'') + m'' \cdot t'';$$

— for the second train :

$$\Sigma T_2 = m_1 (t_1 + t_2 + t_3) + m_2 (t_2 + t_3) + m_3 \cdot t_3.$$

With this method, it is assumed that the sum of the areas of the rectangles which represent the losses in wagon round-trip time due to marshalling, is equal to the area of the triangle with a base $t' + t''$, or $t_1 + t_2 + t_3$, and with the altitude $m$.

It follows that :

$$\Sigma T = \frac{m}{2} (t' + t'') + \frac{m}{2} (t_1 + t_2 + t_3)$$
$$= \frac{m}{2} (t' + t'' + t_1 + t_2 + t_3)$$

In practice, the marshalling of wagons over a period of 24 hours, at one yard and for one direction, might roughly correspond to the distribution shown in figure 5.

On the same assumption, viz. that the sum of the areas of the rectangles is equal to the area of the triangle, and that, furthermore, $t' + t'' + t_1 + t_2 + t_3 = 24$ hours, the sum of the losses in wagon round-trip times occasioned by the marshalling of the wagons at one yard and for one direction or one batch is therefore :

$$\Sigma T = \frac{m}{2} \cdot 24 = 12\, m$$

If, during the 24 hours, $N_x$ wagons have been despatched in the direction X, the average loss of time per wagon is :

$$t_{xAns} = \frac{12\, m}{N_x}$$

If a yard despatches trains in $k$ directions, and dispatches altogether N wagons in all directions, the average time spent by the wagons in the yard due to marshalling amounts to :

$$t_{Ans} = \frac{12\, m\, k}{N}$$

*Second method.* — This time the following assumptions are made :

(1) the average length of the trains, arriving as well as departing, is always the same, or in other words, all trains are formed of the same number of $m$ wagons;

(2) the arriving and departing trains are evenly distributed over the timetable;

(3) every train conveys wagons for all directions, and the number of wagons destined for each direction in each train is proportionate to the number of wagons to be dispatched in these directions every 24 hours.

On these assumptions, and assuming that the number of wagons using yard A in 24 hours is equal to N, and that the composition of the trains is $m$ wagons, the number of trains arriving during that period is :

$$\frac{N}{m}$$

During that time, the interval between train arrivals is :

$$\frac{24\ m}{N}$$

Let us assume that the wagons for different destinations are represented by :

$$N = N_x + N_y + N_z + \ldots + N_k.$$

Each train will thus convey the following number of wagons for X :

$$\frac{N_x \cdot m}{N}$$

In order to form a train of $m$ wagons for X, the following number of trains must have arrived at the yard :

$$m : \frac{N_x}{N} \cdot m = \frac{N}{N_x}$$

It follows that the total time lost per train in order to assemble $m$ wagons, expressed in wagon-hours, amounts to :

For the first partial batch :

$$\frac{N_x \cdot m}{N} \cdot \frac{24\, m}{N} \cdot \left(\frac{N}{N_x} - 1\right)$$

For the second partial batch :

$$\frac{N_x \cdot m}{N} \cdot \frac{24\, m}{N} \cdot \left(\frac{N}{N_x} - 2\right)$$

For the last-but-one partial batch :

$$\frac{N_x \cdot m}{N} \cdot \frac{24\,m}{N} \cdot 1$$

and for the last partial batch :

0 (nought).

The total of these wagon-hours amounts to :

$$\Sigma T = \frac{N_x \cdot m}{N} \cdot \frac{24\,m}{N} \cdot \left[1 + 2 + 3 + \dots + \left(\frac{N}{N_x} - 2\right) + \left(\frac{N}{N_x} - 1\right)\right]$$

or :

$$\Sigma T = \frac{12 \cdot m^2}{N} \cdot \left(\frac{N}{N_x} - 1\right)$$

In consequence, the average time per wagon in the direction X amounts to :

$$t_{xAns} = \frac{12\,m}{N} \cdot \left(\frac{N}{N_x} - 1\right)$$

and for the direction Y :

$$t_{yAns} = \frac{12\,m}{N} \cdot \left(\frac{N}{N_y} - 1\right)$$

The total time in wagon-hours required for the marshalling of all the wagons is therefore :

$$N \cdot t_{Ans} = \frac{12\,m}{N} \cdot \left(\frac{N}{N_x} - 1\right) \cdot N_x + \frac{12\,m}{N} \cdot \left(\frac{N}{N_y} - 1\right) \cdot N_y + \dots + \frac{12\,m}{N} \cdot \left(\frac{N}{N_k} - 1\right) \cdot N_k$$

$$= \frac{12\,m}{N} \cdot \left[(N - N_x) + (N - N_y) + \dots + (N - N_k)\right]$$

$$= \frac{12\,m}{N} \cdot \left[N \cdot k - (N_x + N_y + \dots N_k)\right]$$

$$= \frac{12\,m}{N} \cdot N \cdot (k - 1)$$

$$= 12\,m\,(k - 1)$$

Hence :

$$t_{Ans} = \frac{12\,m}{N} \cdot (k - 1)$$

With the first method, we obtained :

$$t'_{Ans} = \frac{12\,m}{N} \cdot k$$

The difference is therefore :

$$t'_{Ans} - t_{Ans} = \frac{12\,m}{N}$$

or, in per cent :

$$\frac{t'_{Ans} - t_{Ans}}{t_{Ans}} \times 100 = \frac{1}{k - 1} \cdot 100$$

By assigning to $k$ a series of numerical values, one obtains for the first member of this equation a corresponding series of values, which are shown in figure 6 and Table 2.

TABLE 2.

| $k$ | $\frac{t'_{Ans} - t_{Ans}}{t_{Ans}} \cdot 100$ |
|---|---|
| 2 | 100 |
| 3 | 50 |
| 4 | 33 |
| 5 | 25 |
| 6 | 20 |
| 7 | 16.6 |

The error, expressed in per cent, incurred by using the first calculation method, is important in relation to the figure obtained from the second method, especially if the number of directions is small (up to 50 per cent for $k = 3$).

As will be gathered from the foregoing, the average time per vehicle required for the marshalling of the wagons is a function of the average number of wagons per train ($m$), the average total number of wagons arriving at the yard (N), and the number of directions converging on this yard ($k$).

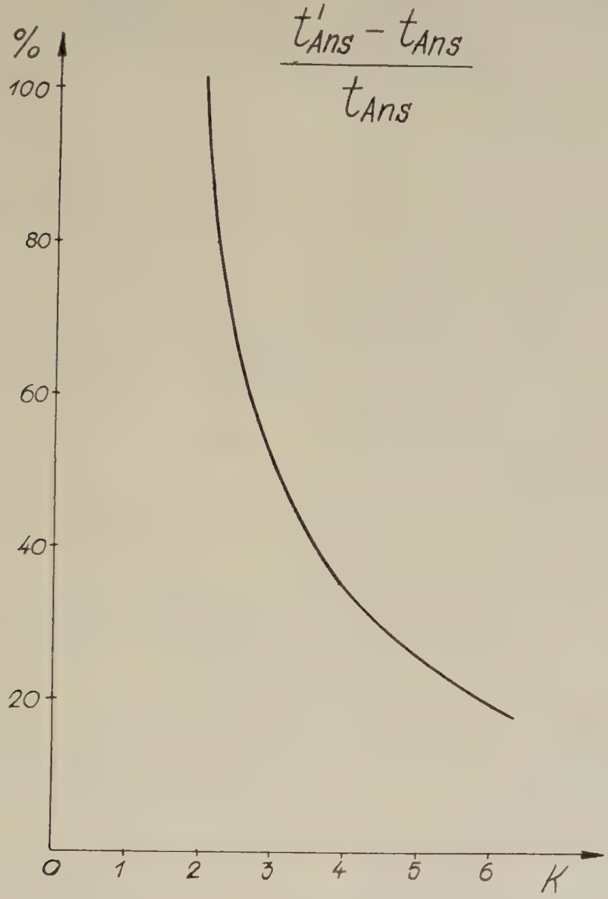

Fig. 6.

Just as the first method for the determination of the average time spent by the wagons is based on the arbitrary assumption that the sum of the areas of the rectangles is equal to the sum of the areas of the triangles, the second method is also based on the erroneous assumption that wagons for X are arriving by all trains, including the trains coming from X, which is obviously wrong.

If, in the course of one day (24 hours), there are N wagons arriving at the yard from the directions X, Y, Z . . . K, and if we denote the batches of arriving wagons by :

$$N' = N'_x + N'_y + N'_z + \ldots + N'_k,$$

it is obvious that, in the course of the day (24 hours) the same number of wagons, $N''$, must leave the yard. This number will consist of $N''_x$ wagons destined for X, $N''_y$ wagons destined for Y, etc.

Hence :

$$N'' = N''_x + N''_y + N''_z + \ldots N''_k.$$

It is a normal feature that, on each line (or rather on each section of line), the number of wagons is generally the same in both directions. This is particularly so when the counts are extended over a sufficiently long period. It is seldom that there is an appreciable difference in the number of wagons in the two directions. On our network, this happens on the line from Zemun to Vinkovci and on certain other sections. For our considerations, however, we can assume that the number of wagons on each line is the same in the two directions in the course of the same day. We can thus write :

$$N'_x + N'_y + N'_z + \ldots + N'_k =$$
$$N''_x + N''_y + N''_z + \ldots + N''_k,$$

or :

$$N'_x = N''_x; \; N'_y = N''_y, \text{ etc.}$$

We are thus able to state, by adhering to the assumptions made above, that although the total number of wagons arriving in the course of the day is equal to N, and that of trains arriving is equal to

$$\frac{N}{m},$$

the total number of trains conveying wagons for X is equal to :

$$\frac{N - N_x}{m}.$$

In consequence, the spacing of the arrivals of these trains is :

$$\frac{24\,m}{N - N_x}$$

The number of trains that must have arrived in order that a train of *m* wagons can be dispatched to X amounts to :

$$m : \frac{N_x \cdot m}{N - N_x} = \frac{N - N_x}{N_x}$$

By using the calculation method already set out above, one obtains :

$$t_{xAns} = \frac{12\,m}{N - N_x} \cdot \left(\frac{N - N_x}{N_x} - 1\right)$$

$$t_{yAns} = \frac{12\,m}{N - N_y} \cdot \left(\frac{N - N_y}{N_y} - 1\right)$$

The total number of wagon hours required for all the wagons is thus :

$$N \cdot t_{Ans} = 12\,m \cdot \left[k - \left(\frac{N_x}{N - N_x} + \frac{N_y}{N - N_y} + \ldots\ldots + \frac{N_k}{N - N_k}\right)\right]$$

Substituting :

$$\frac{N_x}{N - N_x} + \frac{N_y}{N - N_y} + \frac{N_z}{N - N_z} + \ldots\ldots + \frac{N_k}{N - N_k} = e$$

one obtains :

$$N \cdot t_{Ans} = 12\;m\;(k - e).$$

We shall now determine the value of $e$.

The batches of wagons for different directions may be equal, or unequal. If they are equal, one obtains :

$$N_x = N_y = N_z = \ldots\ldots = N_k = \frac{N}{k}.$$

In this case, $e$ assumes the specific value $e_{gl}$ which is expressed by the following equation :

$$e_{gl} = \frac{\frac{N}{k}}{N - \frac{N}{k}} \cdot k = \frac{k}{k - 1}$$

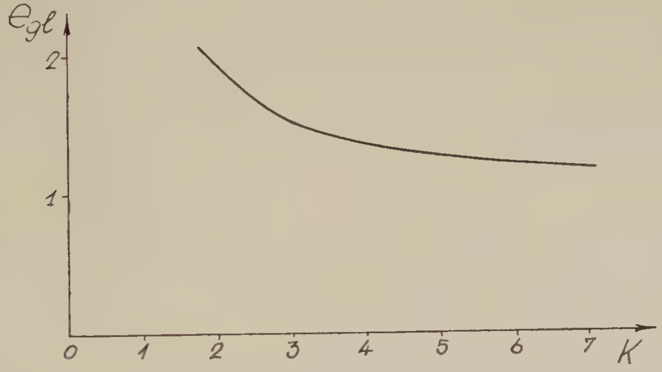

Fig. 7.

By assigning to $k$ a series of numerical values, one obtains a corresponding series of values for $e_{gl}$, as shown in figure 7 and Table 3.

TABLE 3.

| $k$ | $e_{gl}$ | $k$ | $e_{gl}$ |
|---|---|---|---|
| 2 | 2.0 | 7 | 1.16 |
| 3 | 1.5 | 8 | 1.14 |
| 4 | 1.33 | 9 | 1.12 |
| 5 | 1.25 | 10 | 1.11 |
| 6 | 1.20 | — | — |

It will be seen that the value of $e_{gl}$ decreases as the number of directions increases, with the result that there is an increase in the total number of wagon hours required for the marshalling of the wagons as well as in the average time per wagon.

If the numbers of wagons for different destinations are not equal, their influence may vary. But there are necessarily certain limits to the individual divergences if it is remembered that we are exclusively dealing with wagons coming from one line and forwarded to another line, and not with wagons arriving at the yard for terminal handling.

On the strength of this consideration, it is possible to determine the limits for the maximum possible divergence.

If N is the number of wagons arriving at one yard from all directions, the maximum possible divergence is encountered if one of the directions accounts for half that number. A greater inequality is not possible as the following considerations will show.

If there are only two directions, A — X

and A — Y, the number of wagons arriving is :

$$N' = N'_x + N'_y$$

and the number of wagons departing :

$$N'' = N''_x + N''_y$$

As, according to our assumption :

$$N'_x = N''_x \text{ or } N'_y = N''_y$$

and as the wagons only enter the marshalling yard in order to be forwarded to another line, one obtains, of necessity :

$$\frac{N}{2} = N_x = N_y$$

If the yard is equipped for several directions, and if the number of wagons arriving are :

$$N = N' = N'_x + N'_y + \dots + N'_k$$

and the numbers of wagons departing :

$$N = N'' = N''_x + N''_y + \dots + N''_k,$$

and seeing that :

$$N'_x = N''_x \text{ and } N'_y = N''_y, \text{ etc.}$$

the maximum divergence will be :

$$N_x = \frac{N}{2};\ N_y = \frac{N_x}{2} = \frac{N}{2^2};\ \dots..$$

$$N_j = \frac{N}{2^{k-1}};\ N_k = \frac{N}{2^{k-1}}$$

In this case, if the marshalling yard is designed for several directions, the inequality of the direction with the lightest traffic (*k*) in relation to the immediately preceding direction (*j*) may be such that the direction with the lightest traffic receives no more than *m* wagons, i.e. only one train, whilst the preceding direction would then receive :

$$\frac{N}{2^{k-2}} - m$$

wagons.

We shall now make the assumption that the two directions with the lightest traffic have the same value, viz.

$$N_k = N_j = \frac{N}{2^{k-1}}$$

It follows that $e$ has now the specific value $e_{ung}$ given by the following equation :

$$\begin{aligned}
e_{ung} &= \frac{N_x}{N - N_x} + \frac{N_y}{N - N_y} + \dots.. \\
&\quad + \frac{N_k}{N - N_k} \\
&= \frac{\frac{N}{2}}{N - \frac{N}{2}} + \frac{\frac{N}{2^2}}{N - \frac{N}{2^2}} + \dots.. \\
&\quad + \frac{\frac{N}{2^{k-1}}}{N - \frac{N}{2^{k-1}}} + \frac{\frac{N}{2^{k-1}}}{N - \frac{N}{2^{k-1}}} \\
&= \frac{1}{2 - 1} + \frac{1}{2^2 - 1} + \dots.. \\
&\quad + \frac{1}{2^{k-1} - 1} + \frac{1}{2^{k-1} - 1} \\
&= \frac{1}{2^{k-1} - 1} + \sum_{n=1}^{n=k-1} \frac{1}{2^n - 1}
\end{aligned}$$

By assigning different values to *k*, one also obtains different values for $e_{ung}$, as shown in figure 8 and Table 4.

In the same way, if the inequality between different directions is characterized by :

$$N_x = \frac{N}{2},$$

the time $t_{xAns}$ would obviously become zero.

With the second method, this time is different from zero, and amounts to :

$$t_{xAns1} = \frac{12\,m}{N} \cdot \left(2\frac{N}{N} - 1\right) = \frac{12\,m}{N}$$

With the third method, this time again becomes zero, because :

$$t_{xAns2} = \frac{12\,m}{N - \frac{N}{2}} \cdot \left(\frac{N - \frac{N}{2}}{\frac{N}{2}} - 1\right) = 0$$

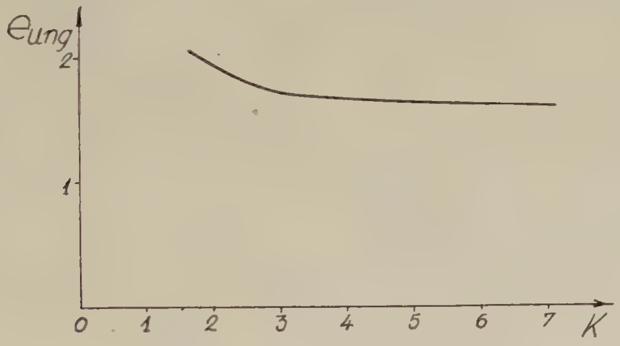

Fig. 8.

TABLE 4.

| $k$ | $e_{ung}$ | $k$ | $e_{ung}$ |
|---|---|---|---|
| 2 | 2.00 | 7 | 1.6069 |
| 3 | 1.66 | 8 | 1.6068 |
| 4 | 1.62 | 9 | 1.6067 |
| 5 | 1.61 | 10 | 1.6067 |
| 6 | 1.6075 | — | — |

As a result, one would have the following three formulas :

$$t_{Ans} = \frac{12\,m}{N} \cdot k$$

$$t'_{Ans} = \frac{12\,m}{N} \cdot (k - 1)$$

$$t''_{Ans} = \frac{12\,m}{N} \cdot (k - e)$$

We have already discussed the discrepancy between the two first formulas. The one existing between the first and the third formula is of a similar magnitude and amounts, expressed in per cent, to :

$$\frac{t_{Ans} - t''_{Ans}}{t''_{Ans}} \cdot 100 = \frac{e}{k - e} \cdot 100$$

We shall now determine the values of $t_{Ans}$ for $m = 40$ wagons, N = 1 000 wagons, and for different values of $k$, by using the given formulas, and shall then examine them. The results are shown in Table 5 and figure 9.

TABLE 5.

| $k$ | $t_{Ans}$ | $t'_{Ans}$ | $t''_{Ans}$ | $t'''_{Ans}$ |
|---|---|---|---|---|
| 2 | 0.96 | 0.48 | 0.00 | 0.00 |
| 3 | 1.44 | 0.96 | 0.72 | 0.64 |
| 4 | 1.92 | 1.44 | 1.27 | 1.14 |
| 5 | 2.40 | 1.92 | 1.80 | 1.63 |
| 6 | 2.88 | 2.40 | 2.30 | 2.10 |
| 7 | 3.36 | 2.88 | 2.80 | 2.58 |
| 8 | 3.84 | 3.36 | 3.30 | 3.56 |
| 9 | 4.32 | 3.84 | 3.79 | 3.54 |
| 10 | 4.80 | 4.32 | 4.27 | 4.02 |

It is the third method which yields the most correct interpretation of the actual position, as will be seen from the following :

If the marshalling yard is working in two directions only, A — Y and A — X (fig. 10), it is obviously unnecessary for wagons to spend any time there because all wagons arriving from the direction Y — A by any train must necessarily continue in the direction A — X, as there is no other choice. In this case there is no difference between the marshalling yard and any line-side station, as the trains will only stop there as long as is necessary for local wagons to be detached or attached. By applying the first and second methods of calculation, one obtains different marshalling times other than zero whilst the third method yields a zero value.

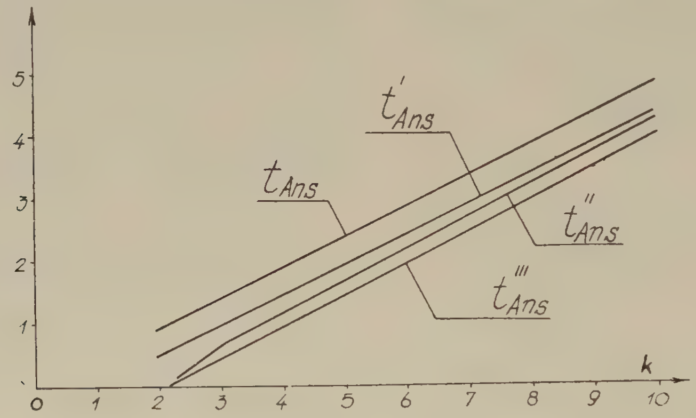

Fig. 9.

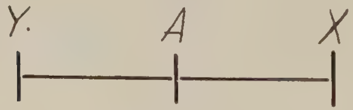

Fig. 10.

The formula :

$$t_{Ans} = \frac{12\,m}{N}\,(k - e)$$

can be written in the form :

$$t_{Ans} \cdot \frac{N}{m} = 12\,(k - e).$$

If we now give different values to $\frac{N}{m}$, i.e. to the number of trains arriving at the marshalling yard, as well as the number of directions ($k$), we obtain different values for $t_{Ans}$ as shown in Table 6.

TABLE 6.

| $k$ | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|
| N/$m$ | $t_{Ans}$ | | | | |
| 10 | 1.8 | 2.86 | 4.07 | 5.26 | 6.45 |
| 20 | 0.9 | 1.43 | 2.03 | 2.63 | 3.22 |
| 30 | 0.6 | 0.95 | 1.35 | 1.75 | 2.14 |
| 40 | 0.45 | 0.715 | 1.02 | 1.32 | 1.161 |

As the table shows, the number of trains arriving, $\frac{N}{m}$, i.e. the volume of traffic N, and the length of the trains, $m$, as well as the number of directions, $k$, have a decisive influence on the value of $t_{Ans}$.

As has already been stated, the time required for marshalling the wagons destined for X is given by the equation :

$$t_{xAns} = \frac{12\,m}{N - N_x}\cdot\left(\frac{N - N_x}{N_x} - 1\right)$$

Through transformation, one obtains :

$$t_{xAns} = 12\left(\frac{m}{N_x} - \frac{m}{N - N_x}\right)$$

Now, $\frac{N_x}{m}$ expresses the number $n_x$ of trains destined for X, and :

$$\frac{N - N_x}{m} = n_{y\cdots k}$$

the number of trains arriving from all directions except X so that one obtains the formula :

$$t_{xAns} = 12\cdot\left(\frac{1}{n_x} - \frac{1}{n_{y\cdots k}}\right)$$

### Determination of the conditions for the formation of direct trains.

In determining the conditions for the formation of batches of wagons for direct trains, the theoretical criterion must be that the total number of wagon-hours (those spent in the marshalling yards where direct trains are formed, as well as those spent in yards where trains pass through without being re-marshalled) must be smaller than the total number of wagon-hours spent at the yards by all batches of wagons if no direct trains were formed.

The criterion for the formation of a direct train is thus given by the formula :

$$N_x > \frac{12\,m}{(t_z - t_{Tr})\cdot D}$$

where $N_x$ represents the minimum average batch of direct wagons to be formed, and D the number of marshalling yards to be passed by this batch.

The above formula is based on the following assumption :

$$12\,m\,D + t_z\cdot N\cdot D + \frac{12\,m}{N}\cdot N\cdot D$$

$$> 12\,m + N_x\cdot t_{Tr}\cdot D + \frac{12\,m}{N_x}\cdot N_x\cdot D$$

$$+ (N - N_x)\cdot t_z\cdot D + \frac{12\,m}{N - N_x}\cdot(N - N_x)\cdot D$$

The first member of this expression represents the number of wagon-hours spent when no direct batches are formed, N signifying the total of all the batches, whilst the second member represents the wagon-hours if a direct batch of wagons is formed for $N_x$, the term $N - N_x$ denoting all the other wagons not included in the direct batch.

The different terms of the first member have the following significance :

$12\,m\,D$ :

number of wagon-hours required for the marshalling of wagons, for D yards;

$t_z\cdot N\cdot D$ :

number of wagon-hours required to form trains, for N wagons and D yards;

$\frac{12\,m}{N} \cdot N \cdot D$ :

number of wagon-hours spent in awaiting the departure time, for N wagons and D yards.

The different terms of the second member have the following significance :

$12\ m$ :

number of wagon-hours required for the formation of the $N_x$ group of wagons at the dispatching yard;

$N_x \cdot t_{Tr} \cdot D$ :

number of wagon-hours required by the direct train, in D yards;

$\frac{12\,m}{N_x} \cdot N_x \cdot D$ :

number of wagon-hours spent by the through train in awaiting the departure time at D yards;

$(N - N_x) \cdot t_z \cdot D$ :

number of wagon-hours required for the forming of trains other than the direct trains, at D yards;

$\frac{12\ m}{N - N_x} \cdot (N - N_x) \cdot D$ :

number of wagon-hours spent by the wagons other than those in direct trains in awaiting their departure time, at D yards.

This thesis cannot be maintained, for the following reasons :

(1) apart from the time required for the marshalling of the wagons, account has been taken of the time spent in awaiting the departure time which would, in our opinion, not correspond to reality, even for direct trains between two successive yards, and still less for a direct through train;

(2) in the case of a direct through train, no account is taken of the time required for the formation of this train, though the time spent at intermediate yards is taken into account and, for that matter, at D stations instead of D — 1;

(3) the time required for the marshalling of batches of non-direct wagons, at D yards, is not included.

We shall now have to say a few words about the feature of " awaiting the time of departure ", and examine the question whether or not this should be taken into account.

It may be assumed that all trains are evenly spread over the timetable. In consequence, apart from the time required for the marshalling of wagons and the formation of the train, account has also been taken of the time spent in awaiting the departure time laid down in the timetable.

This waiting time can be theoretically determined as follows, using the formula :

$$t_{Ans} = \frac{12\,m}{N}\,(k - 1)$$

We shall here take as an example a marshalling yard with only two directions.

The reasoning is as follows. As the arrival intervals for the trains from the two directions is $\frac{24\ m}{N}$, the probable departure interval for direct trains in one direction must be $\frac{12\ m}{N}$.

It must also be considered that if all the wagons for one direction are only taken by a direct train as far as the next yard, the probable duration of the waiting time will amount, by reason of the arguments set out above, to $\frac{12\,m}{N}$.

But if, from among all the wagons for one direction, a certain number are taken away which must be dispatched as direct trains passing through several yards without being re-marshalled there, as for example the $N_3$ group in figure 3, whilst the remainder continue to be taken by direct train to the next yard, the duration of the waiting time will be $\frac{12\,m}{N_3}$ for the direct train passing through several yards, and $\frac{12\ m}{N - N_3}$ for the direct train serving the first yard only.

It follows that the time spent in awaiting the hour of departure is shorter for a direct train destined for the first yard than for a direct train destined to pass through several yards, as there is always :

$$\frac{12\,m}{N_3} > \frac{12\,m}{N}$$

But if all the wagons not intermediately re-marshalled are dispatched together as far as X, the interval between the departure times of the trains is increased to $\frac{24\ m}{N_x}$, and can therefore not be equal to $\frac{12\ m}{N}$.

Now, if one takes away from $N_x$ a certain number of wagons $N_3$ which are to be dispatched in direct trains passing through several yards, whilst the remaining wagons $N_x - N_3$ continue to be dispatched in direct trains going as far as X only, the departure interval is :

$$\frac{24\,m}{N_3}$$

for trains of the first type, and :

$$\frac{24\,m}{N_x - N_3}$$

for trains of the second type.

It is not possible to tell beforehand which of these two intervals is greater as the answer to this question depends on the relative magnitude of the values $N_3$ and $N_x$.

If

$$N_3 = \frac{N_x}{2},$$

these times are equal. For

$$N_3 > \frac{N_x}{2},$$

one obtains :

$$\frac{24\,m}{N_3} < \frac{24\,m}{N_x - N_3},$$

and finally, for :

$$N_3 < \frac{N}{2},$$

one obtains :

$$\frac{24\,m}{N_3} > \frac{24\,m}{N_x - N_3}.$$

It is therefore relevant to put the question whether, in addition to the time required for the marshalling of wagons ($t_{Ans}$) and the time required for the marshalling of the trains ($t_z$), it is necessary also to take into account the time spent in waiting for the departure time, as is usually done in technical literature.

In our opinion, it is erroneous to take this waiting time into account.

If the departure interval for wagons destined for X is $\frac{24\,m}{N_x}$, it must be equal to the time required to marshal *m* wagons which have arrived by trains from the directions Y . . . K.

In order to marshal *m* wagons, the following number of trains must have arrived from the directions Y . . . K :

$$m : \frac{N_x \cdot m}{N - N_x} = \frac{N - N_x}{N_x}.$$

Their interval is :

$$\frac{24\,m}{N - N_x}$$

so that the time required for the marshalling of *m* wagons for X amounts to :

$$\frac{N - N_x}{N_x} \cdot \frac{24\,m}{N - N_x} = \frac{24\,m}{N_x}.$$

The departure interval of the trains is thus equal to the time required for the marshalling of the wagons. There is therefore no reason to take into consideration the time spent in awaiting departure, in addition to the time required for the marshalling of the wagons.

If all the above observations are taken into consideration, the criterion for the formation of direct batches of wagons works out as follows :

$$12\,m\,D + t_z \cdot ND > 12\,m + t_z \cdot N_x + t_{Tr} \cdot N_x \cdot (D - 1) + 12\,m\,D + t_z \cdot (N - N_x) \cdot D.$$

Hence :

$$N_x > \frac{12\,m}{(t_z - t_{Tr}) \cdot (D - 1)}$$

---

But this condition alone is not yet sufficient. For one thing, one has made the assumption that the loss in wagon-hours for the marshalling of all the wagons for one direction, or of a partial batch, is 12 *m*, which is not accurate as the assumption depends on the number of directions or groups. Moreover, it is not possible to neglect the fact that, in the case of the formation of a direct batch, the value *k* must be replaced by *k* — 1.

Let us assume that, in the example given earlier on, there was :

$$N_1 + N_2 + N_3 = N_x;$$

$$N_2 + N_3 + N_4 + N_5 = N_x;$$

$$N_3 + N_5 + N_6 = N_x.$$

Let us further assume that the number of directions departing from yard A as well as from yards X, B and C is equal to *k*, and finally that the total number of wagons arriving at A, X, B, and C is equal to N. If it is intended to dispatch batch $N_3$ direct from A to C, the following conditions must be fulfilled :

$$\frac{12\,m\,(k - e)}{N} \cdot N_x D + t_z \cdot N_x \cdot D$$

$$> \frac{12\,m\,(k + 1 - e)}{N} \cdot N_3 + t_z \cdot N_3$$

$$+ t_{Tr} \cdot N_3\,(D - 1) + \frac{12\,m\,(k + 1 - e)}{N}$$

$$\cdot (N_x - N_3) \cdot D + t_z \cdot (N_x - N_3) \cdot D$$

Hence :

$$N_3 > \frac{12\,m\,N_x \cdot D}{[N \cdot (t_z - t_{Tr}) + 12\,m\,(k + 1 - e)] \cdot (D - 1)}$$

Let us now assume the following numerical values : $N = 1\,000$ wagons, $m = 40$ wagons, $N_x = 240$ wagons, $D = 4$, $t_z = 3$ hours, $t_{Tr} = 1$ hour and $k = 4$. According to the formula given in literature, the condition for the formation of a direct group is :

$$N_3 > \frac{12 \cdot 40}{(3 - 1) \cdot 4} = 60 \text{ wagons,}$$

According to the corrected formula, the condition is :

$$N_3 > \frac{12 \cdot 40}{(3 - 1) \cdot (4 - 1)} = 80 \text{ wagons,}$$

Finally, according to the formula worked out above, taking the value of $e_{gl}$ as corresponding to $k = 5$ :

$$N_3 > \frac{12 \cdot 40 \cdot 240 \cdot 4}{[1\,000 \cdot (3 - 1) + 12 \cdot 40\,(4 + 1 - 1.25)\,] \cdot (4 - 1)} \simeq \text{say, 42 wagons.}$$

As these considerations show, it is necessary if it is desired to segregate a batch $N_3$ of wagons for direct dispatch, to take into account not only the volume of the batches $N_x$ already existing (from which $N_3$ is taken) but also the number of marshalling yards which the train must pass without being re-marshalled there, as well as the yard where the batch is being segregated, the number of directions ($k$) in these yards, and the total volume of traffic (N) handled by them.

[ 625 .251 ]

# Recent progress in the braking of trains,

by Laplaiche,

Chef de la Division des Essais de Matériel de la Société Nationale des Chemins de fer français.

(*Chemins de fer*, November-December 1955.)

*Railways in general, and the S.N.C.F. in particular, have made such progress in the last few years as must impress even the least observant. The catenary networks stretching out above the lines and the lithe and powerful electric locomotives which are taking the place of the Pacifics and Mountains, are evident to all. It is well known, too, that speeds are higher on electrified lines — a glance at the timetable is revealing in this respect. Increased comfort in the coaches, smooth running — the happy product of improved suspension and perfectly constructed track — and thorough sound insulation are also to be remarked. If regularity of service, which is so much appreciated by passengers, and several notable records are included, it becomes clear that every traveller must be aware of the extent of the technical progress achieved by the French Railways.*

*In the midst of all this there is little mention of braking. The impression received even by the well informed is that progress has not kept pace in this field. The familiar sound of brake shoes on the wheels before station stops remains the same and the hiss of escaping compressed air when the brakes are released has not changed its note. Here too, however, there is progress, although it may be said that the development of brakes has been somewhat cautious. It must be remembered that, in the case of brakes, progress is confined within narrow limits, since different types of brake may need to be interworked, under conditions covered by a set of regulations laid down at international level. Within the last few years five new systems of braking have been submitted to the International Union of Railways for their agreement. All of them involve new techniques. Moreover, it is clear that increased weights and speeds have created and continue to create braking problems which are not always easily resolved. But we are anticipating. The purpose of this article is to trace the progress recently made in the field of braking apparatus and to discuss the problems on which research and experiment are going on.*

## SUMMARY OF SOME BASIC PRINCIPLES

Before tackling the main issues it would appear useful to recall certain principles which will be referred to in the course of the discussion and which must be firmly grasped if the problems of braking are to be understood.

One of the most important is the conception of a vehicle's weight to be braked. This weight to be braked describes the efficiency of the vehicle's brake equipment in a particular type of brake application. It is expressed in tons. It must be known to calculate braking scales and braking distances. Clearly a vehicle's capacity to stop within a given distance is a function of the weight to be braked and the tonnage. The relationship between the weight to be braked and the weight on the rails is referred to by the expression " coefficient of braking (λ) ".

A train's weight to be braked is the sum of those of the vehicles of which it consists and the λ of the train, which expresses its capacity for pulling up is this sum divided by the total weight of the train.

If the definition of a vehicle's weight to be braked given in I.U.R. (U.I.C.) leaflet 544 is examined, it is found that there is a difference between that of vehicles fitted for freight train operation and those fitted for passenger train operation. This can be explained historically.

Originally, there was no compressed air brake on wagons. There were only hand brakes. It was estimated that a brake application of average power achieved a force at the brake shoes equal to 7/10 of the weight of the wagon being braked and the braking power of such a vehicle thus came to be expressed by its weight on the rails.

The " weight to be braked " being equal, as thus defined, to the weight on the rails, was thus 10/7 of the force exerted at the brake shoes.

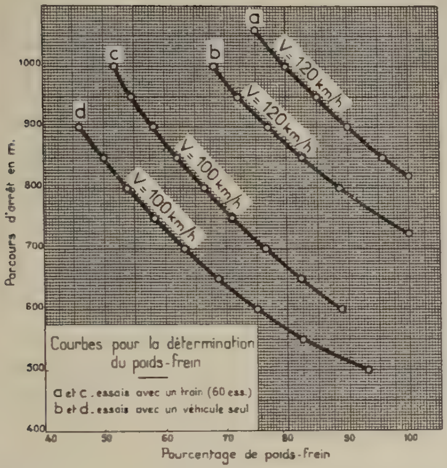

Fig. 1. — I.U.R. (U.I.C.) curves giving braking distances as a function of braking weight.

*Explanation of French terms :*

Parcours d'arrêt en m = braking distance (in metres). — V (vitesse) = S (speed). — Pourcentage de poids frein = percentage of weight to be braked. — Courbes pour la détermination du poids-frein = curves for determining the weight to be braked. *a* and *c* = tests with train of 60 axles. — *b* and *d* = tests with a single vehicle.

As a result, when the air brake was introduced on wagons, the value 10/7 of the force realised by this air brake at the brake shoes was naturally used to express the weight to be braked. But it was soon observed that the characteristics peculiar to the air brake were quite different from those of a brake operated by hand. The efficiency of the air brake depends in the main on the time required to apply it and on the strength of the force exerted at the shoes at the end of the initial admission in relation to that ultimately exerted. These factors may vary from one brake to another to such an extent that it has proved necessary to modify the figure 10/7 of the force exerted at the shoe, by using a coefficient $\gamma$ which is determined by the type of equipment. This is how the definition given in I.U.R. leaflet 544 of the weight to be braked of a wagon fitted with air brakes for freight train service is obtained.

The values of the coefficient $\gamma$ are given in the tables appended to leaflet 544. They are a function :

- of the actual force $p$ exerted on the shoe, during running and with average length of travel of the piston,
- of the ratio $a$ between the force exerted at the shoes at the end of the first stage of the application and the force ultimately exerted,
- of the duration of the complete application $t$, for an average length of travel of the piston, measured from the moment when the air begins to enter the cylinder to that when the force reaches 95 % of its eventual strength.

To quote actual figures, $\gamma = 1$ when $p = 1\,690$ kg, $a = 20\,\%$ and $t = 28$ s.

When the weight to be braked has been determined in this way, the results are used, in conjunction with scales, when providing braking power on freight trains. The scales used give, in general, a braking power with a wide margin of adequacy. So far as the calculation of stopping distances is concerned (though these are rarely calculated in the case of freight trains) the traditional formula of Maison is still used.

So far as the passenger brake is concerned, the weight to be braked is calculated in a different way. Firstly, the characteristics of a passenger train brake are such that the concept of 10/7 of the force at the shoes is almost without significance, and it is thus preferable to ignore it.

Moreover, the application time of the passenger brake is very short and the first stage is non-existent, so that the coefficient $\gamma$ has, for a given force at the shoes, substantially the same value for all types of brake. As a result of this the coefficient can be ignored. It has, in fact, been established that the passenger train weight to be braked can be calculated on the results of practical tests.

First it was assumed, by definition, that a vehicle 50 t (*) in weight, with two two-axle bogies and braked by sixteen cast iron brake shoes, with a total force exerted at the shoes of 40 t, had a weight to be braked of 50 t.

The unit of the weight to be braked being thus defined by this " standard vehicle ", the ratio of a particular vehicle's weight to be braked to that of the standard vehicle was defined as the ratio of the weights of two trains, consisting of the same number of vehicles, one of the standard vehicle and the other of that under test, able to stop from a speed of 120 km/h (74.5 m.p.h.) within 1 000 m, by an emergency application of the brakes. It soon became apparent, however, that this definition was somewhat imprecise, since the standard vehicle's weight to be braked may vary within considerable limits, while the characteristics of the cast-iron of the brake shoes also vary.

The definition was therefore abandoned and a direct definition of the weight to be braked was obtained by taking the stopping distance actually realised by a particular train consisting of the vehicles under test and starting from a given speed.

Since the braking potential of a train depends on the train's braking coefficient $\lambda$, the value $\lambda = 0.80$ was attributed to a train of fifteen coaches, coming to rest within 1 000 m from 120 km/h.

Having fixed this definition the I.U.R. (U.I.C.) then established, by means of numerous tests, the curves shown in figure 1, which give the stopping distances for a train and for a single vehicle, for speeds of 100 km and 120 km/h as functions of their coefficients of braking. It should be noted that the stopping distances of a single vehicle are shorter, for a given $\lambda$, than are those of a train. This results firstly from the fact that the movement resistance (including wind resistance) of a vehicle considered by itself is greater than when it forms part of a train, and secondly from the fact that the brakes of a single vehicle take effect more quickly than when the vehicle is placed half way along a train. But the determination of the braking distance leads to the same result whether a single vehicle or a train of fifteen coaches is considered, since the curves which have been cited are themselves the results of experiment.

The information provided by these curves, which are valid for 100 and 120 km/h were supplemented by the O.C.E.M. (*) about 1937, under the guidance of Mr. Pedelucq. This experiment made it possible to establish an equation, valid for speeds from 70 to 140 km/h which gives the stopping distance in terms of the coefficient of braking $\lambda$, the gradient $i$ and the speed $v$.

This equation is as follows :

$$L = \frac{\varphi V^2}{1{,}094\,\lambda + 0{,}127 - 0{,}235\, i\, \varphi}$$

where $\varphi$ is an empirically established coefficient which varies with the speed as shown in the table (fig. 2).

Values of $\varphi$

| Speed in km/h | $\varphi$ |
|---|---|
| 70 and 71 | 0,061 |
| 72 to 76 | 0,062 |
| 77 to 88 | 0,063 |
| 89 to 98 | 0,064 |
| 99 to 104 | 0,065 |
| 105 to 109 | 0,066 |
| 110 to 112 | 0,067 |
| 113 to 116 | 0,068 |
| 117 to 119 | 0,069 |
| 120 to 123 | 0,070 |
| 124 to 126 | 0,071 |
| 127 to 133 | 0,072 |
| 134 to 140 | 0,073 |
| 160 | 0,075* |

* Provisional figure.

Fig. 2. — Table giving values of $\varphi$ in terms of speed.

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(*) 1 tonne = 1 000 kilogrammes.

(*) *Translator's Note :* O.C.E.M. (Office Central des Essais de Matériel) = Central Equipment Testing Office.

It should be added that the I.U.R. leaflet 544 also recognises that the " passenger " weight to be braked may be arrived at by calculation. In this case the equation B = PK is used, B being the weight to be braked, P the total force exerted at the shoes in tonnes, measured while running and K is a factor which depends on the force exerted per shoe P/*c*, which is given in a table appended to the leaflet. This force can also be measured at standstill, by taking 9/8 of the force measured on the stationary vehicle without knocking the brake rigging.

This method only gives approximate results. It is only allowed on systems the lines of which do not permit tests to be conducted at 100 km/h or more. It is also used extensively in design offices since, starting from the characteristics of the brake equipment, the order of magnitude of a vehicle's weight to be braked can be determined before the vehicle is built.

However, only tests on the line can give exact results and the fly shunt method is much used, particularly for single vehicles, since it is quick and has considerable intrinsic value.

Readers of this article may be interested in how it is carried out on the S.N.C.F.

An electric locomotive with powers of rapid acceleration, such as a CC 7 100, is used, attached to the vehicle to be tested by coupling gear which can be released from the trailing vehicle, whilst it is in motion, by means of a pulley. The vehicle's brakes are charged before departure, the brake connections are uncoupled and the locomotive starts off. The locomotive is driven in reverse, so that the motorman can communicate by signs with the brakeman in charge of the pulley. Naturally another member of the footplate staff rides in front to check signals. When a speed slightly above test speed has been reached, the current is cut off and, at the exact moment that the intended speed is reached, the coupling is lifted. At that moment the locomotive accelerates rapidly in order to get clear and the vehicle's brakes are applied when passing a hundred metre post. The vehicle stops, while the locomotive remains a convenient distance away. After the test the locomotive returns to the vehicle and tests can be started again. In this way, a large number of tests can be made and the method has proved to be very convenient and precise.

Locomotives too have a weight to be braked and this is different for passenger and freight working. The passenger weight to be braked, which must be found when brakes for high speed trains are being considered, can be established by a fly shunt test. But it is very difficult to get a useful value for the freight train weight to be braked, through the very nature of the brake (in particular its extended application time). Clearly, the coefficient $\gamma$, which was previously applied, cannot be used, in view of the rate of increase of pressure in the cylinder in terms of time where locomotive apparatus is concerned (no initial admission). It would appear possible to devise an experimental fly shunt method which would give a value that could be used in braking tables, but so far, on the international level at any rate, this has not been done. Moreover, in most cases the braking of freight trains is ample in relation to the speeds achieved, even though the locomotive has no weight to be braked beyond that which is required to stop it itself within the sighting distance of the signals.

The concept of weight to be braked, which is purely empirical, may appear somewhat strange. In fact, it is a useful instrument in the study of braking and it gives satisfactory results. It is at any rate an improvement on the old concept, still sometimes used, which defined the coefficient of braking as the ratio between the force exerted at the shoe and the weight on the rails. This can be seen simply by considering the equation B = PK which has already been quoted and by noting the variations in K in relation to the force exerted per shoe.

The existence of two different definitions for passenger and freight traffic weights to be braked may seem peculiar. It is in fact the case that a " tonne " of passenger

Tests on the Toulouse-Pau line, 15th and 16th November 1955. Locomotive 2D2 5507 at Montrejeau station.
(Photo A.F.A.C.).

Tests on the Toulouse-Pau line, 15th and 16th November 1955. Locomotive CC 7113 at Montrejeau station.
(Photo A.F.A.C.).

traffic " weight to be braked " is not equivalent to a " tonne " of freight traffic " weight to be braked ".

The reasons for this state of affairs have been explained. There is no doubt that a straightforward method of determining the freight traffic weight to be braked, which would be analogous to that used for passenger vehicles, could be envisaged. But, before existing methods are altered, the need to reconcile, without too much disturbance, the scales using the " weight to be braked tonne " with those using the old units must be borne in mind. In practice, the need to revise the concept of freight train weight to be braked has not yet become pressing. Perhaps it will be different when brake design has made such progress that the characteristics of passenger and freight traffic brakes become very similar to one another.

This section, which is already too long, will be closed with a few figures.

A passenger coach which is to be included in a train running at 140 km/h must have a λ of from 105 to 115 % according to its weight. (Lightweight coaches have to have a higher λ than heavyweight, so as to compensate for the almost universal inadequacy at these speeds of locomotive weights to be braked.)

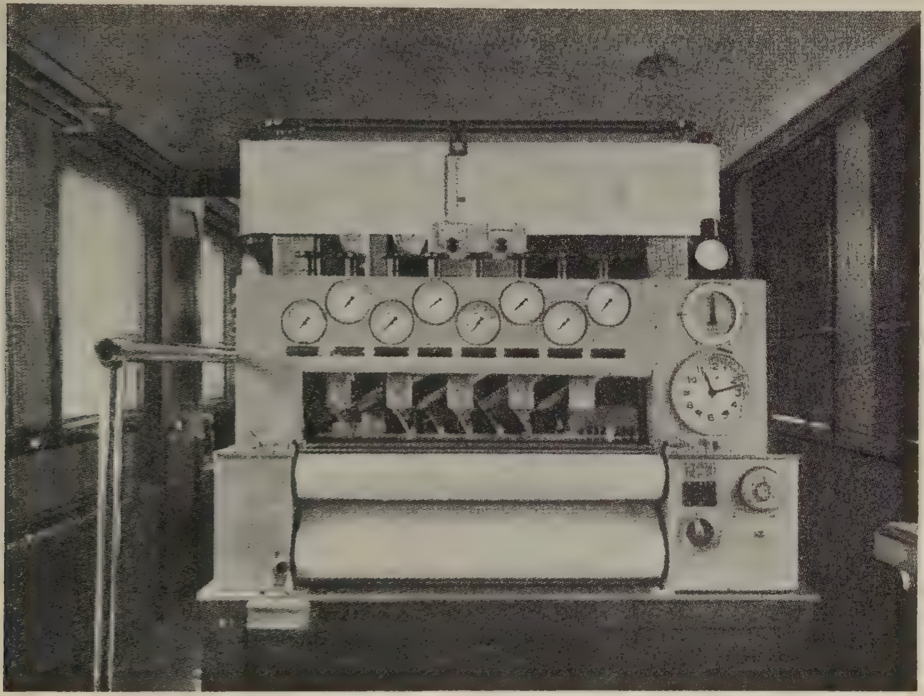

Fig. 3. — Amsler table in dynamometer car No. 1, for brake recording.

With an ordinary brake, a λ of 120 % cannot be greatly exceeded without risk of skid.

Operation at 160 km/h requires a λ for the train of about 125 %, which, when the locomotive is taken into consideration, entails coaches with a λ of 150 to 160 %. This can only be achieved, as will be shown later, by special high power brake equipment.

Modern type steam locomotives, such as

4-6-2's, have λ's of no more than 50 %. Recent designs of electric locomotives for fast trains, such as the CC 7 100 for example, have a λ of the order of 80 %. An account will now be given of certain features common to all continuous brakes.

— *The speed of transmission of braking* is the quotient of the length of pipe (from the driver's valve to the stop valve at the tail end), divided by the length of time which elapses from the moment when the driver puts the handle of his valve in the braking position to that when the air begins to enter the brake cylinder of the last vehicle (transmission time).

This speed is of great importance, particularly in the smooth running of a train during braking. The speed required of modern brakes is 250 m a second for a quick application. It should be observed that the definition of transmission time includes a " dead " period, the length of which depends on the type of equipment on the locomotive, since this period is calculated from the time when the valve handle is put in the braking position. This period is particularly significant in the case of a moderate application of the brakes (the delay being due to the operation of the equaliser on the driver's valve) and it reduces the speed of operation somewhat more on short trains than on long trains. In certain circumstances, it may be more valuable to measure the transmission speed by taking the time which elapses between the entry of the air into the cylinders of the first and last vehicles.

— The *braking time* of a vehicle considered by itself is the time that elapses between the moment when the air begins to enter the brake cylinder and that when the pressure reaches 95 % of its maximum. This period should be 3 to 5 s in passenger train operation and 20 to 28 s in freight train operation. It may be remarked that the latter figures have been laid down quite recently. Formerly they were 30 to 40 s.

— The *brake release time* of an isolated vehicle, after a *complete brake application*, is the time that elapses between the moment when the air begins to escape from the cylinder and that when the pressure reaches 0.4 kg/cm$^2$ (at this point the braking force is practically nil). This time should be within the limits 45 to 60 s in freight operation and 15 to 20 s in passenger train operation. In the case of a complete train, the time taken is that which elapses between the start of the release operation and the time when the pressure in the last vehicle's brake cylinder has fallen to 0.4 kg/cm$^2$. This time should not be more than 70 s in the case of a freight train (150 axles, 3/4 of them braked) or 25 s in passenger train operation ( a train of fifteen 4-axle vehicles or thirty 2-axle vehicles, all of them braked).

— *Inexhaustibility* is a feature required in all brake systems, since it ensures safety on long and steep falling gradients. In actual fact, no brake is completely inexhaustible but, according to the specifications of I.U.R. leaflet 540, it is considered as such when, after manipulation of the driver's valve in any manner whatever, a rapid application of the brakes on a given train produces a pressure in the vehicle's brake cylinders equal to 85 % of the normal total pressure. It is specified that these operations should not include leaving the valve in the neutral position for a long period nor should the pressure created in the brake cylinders be less than 0.3 kg/cm$^2$. The explanation of this important qualification will be given later.

## EXPERIMENTAL WORK CARRIED OUT ON THE S.N.C.F. IN THE STUDY OF BRAKING

The experiments required to perfect new brake apparatus and the theoretical work related to it are carried out by a special section the Brake Testing Section (Section des Essais de Frein — S.E.F.) which is part of the Equipment Testing Division (Division des Essais de Matériel — D.E.M.).

The S.E.F. has the facilities required to measure transmission speeds, carry out timings, measure pressures, forces, heating, supply of air, etc., both at rest and when running, for single vehicles as well as for the longest trains. Measurements taken are generally recorded on “ Amsler ” tables. Further, one of the former dynamometer cars of the O.C.E.M. has recently been converted into a special brake testing car (V. D. No. 1). It has been equipped with a multiple recording “ Amsler ” table of the latest type and also with all the measuring instruments required to test brake transmission apparatus (fig. 3). In particular, it was used for international tests of the Westinghouse E 2 brake in October 1955. The car is equipped in an up-to-date manner which enables precise measurements to be made.

As a matter of historical interest, we may mention that the O.C.E.M. dynamometer cars with Amsler equipment, which were built in 1932 for use in locomotive testing and were used on various systems over a period of many years, witnessed notable performances by steam locomotives when at the peak of their development. These cars, too, have altered. Car No.1 is now the “ brake car ” of the S.N.C.F. No. 2 has been converted into an “ electro-technical car ” and is used by the Electric Traction Research Department (Division des Etudes de Traction Electrique) for experiments with locomotives. No. 3 has been equipped with measuring apparatus required for track tests connected with sound insulation. It is used by the Sound and Heat Insulation Research Section (Section des Etudes d’Insonorisation et d’Isolation Thermique) of the D.E.M. No. 4 remains in its original condition.

There is also, at Vitry Testing Station, a machine for testing brake shoe castings (fig. 4 and 4(*a*)). This machine enables coefficients of friction and wear to be measured either during sustained braking or braking with falling speed (braking to a stop) (*Revue Générale des Chemins de fer*, Jan.- Feb. 1941). It is soon to be rebuilt in such a way that it will be possible to take observations under conditions more closely approaching reality. At present, the energy stored in the flywheel is absorbed by braking a single wheel. In a vehicle, the mass equivalent to that of the flywheel would be about 9 t, which corresponds to 72 t for a 4-axled vehicle — that is about twice the weight of present day French coaches. The alterations consist in placing next to the machine a structure consisting of two linked wheels, both driven by the same flywheel, to which the brake will be applied. The mass to be braked on each wheel will thus be divided by two.

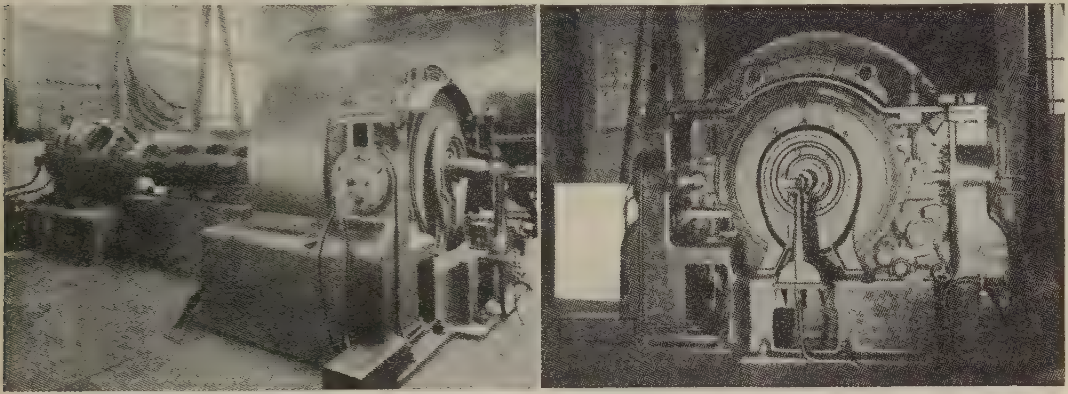

Fig. 4 and 4(*a*). — Brake shoe testing machine at Vitry.

The apparatus comprising the two additional wheels will have its own equipment for measuring tangential and radial forces which will, moreover, be based on a principle which will enable more precise measurements to be taken than is at present the case.

Finally the S.E.F., in certain tests, sometimes has recourse to the most up-to-date measurement techniques, such as electronics and oscillographic mountings. (This was recently done to measure precisely the very high transmission speeds achieved with the electropneumatic brakes which are at present the subject of experiment.) The S.E.F. on this occasion received help from another section of the D.E.M. which possessed the necessary apparatus (Contruction Testing Section - Section des Essais de Construction).

Brakes are components of prime importance in connection with safety of operation. Their testing must always be carried out with great care and precision and a long period of time is sometimes required.

For example, the testing of a new type of distributor (*), with the object op placing it in international service, is an important operation which takes several months. During these trials, which are carried out both when stationary and when running on level and on steeply graded lines, the new distributor is subjected to a great many tests, the aim of which is to reveal any irregularities which might appear under the most severe service conditions and also to check that it fulfills the twenty requirements laid down. When the developmental work is considered satisfactory, the brake is submitted to a specialist sub-committee consisting of engineers from various European countries. This process itself includes many tests. It lasts about a fortnight and follows a programme based on I.U.R. leaflet 547 concerning which we cannot go into detail here.

## MAIN CHARACTERISTICS OF AUTOMATIC COMPRESSED AIR BRAKES. — TECHNICAL DEVELOPMENT

### General.

It is not intended to go over the way in which the automatic compressed air brakes used on railway vehicles work. It is assumed that this is well known to the reader. It should be recalled that the property of being automatic rests in the fact that, after the brake has been charged, there is a reservoir of compressed air on each vehicle which is used to apply the shoes and which is replenished after each application. It should also be recalled that there are two main types of brake : brakes which can be controlled during release, that is which allow for " steps " of braking during the release period, and brakes which cannot be controlled during release, sometimes called direct release brakes, which do not allow for such " steps " and which produce complete release as soon as the process is initiated. (Brakes of both types can be controlled *during application*) (diagram in fig. 5.)

If these two types of brake are considered from the point of view of " convenience " in the braking of railway vehicles, the first consideration which springs to mind is simple : it may seem *a priori* convenient to have a brake which can be operated either so as to increase the application or so as to reduce it. If the matter is considered further, it becomes evident that this convenience is primarily concerned with the concept of ease of handling of the brake. Anyone who has had to make controlled stops with heavy trains by using the brake valve of a locomotive, will be well aware of this. His ideal brake (and that of the passengers as well ) would be like a motor car brake. This is recognised as being thoroughly convenient because it is fully adjustable in that it responds immediately to demands either to increase or to reduce it. These conditions are certainly not fulfilled on railways at present (though they may reasonably be postulated as an aim). The fact is that railway brakes respond

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(*) *Translator's Note :* This article contrasts new types of " distributeur ", such as the Oerlikon Est 3 d with the older " triple valve " type. The English catalogue of the Oerlikon Est 3 d, prepared by Davies and Metcalfe Ltd. refers to this apparatus itself as a triple valve. However, in order to preserve the distinction which is made in the article, the term " distributor " has been used where appropriate throughout this translation.

slowly. On application the transmission time for a long train lasts several seconds. The application time also must therefore be several seconds long, in order to achieve a virtually simultaneous application of the brakes at the head and the rear of the train and so ensure smooth braking. On release, the locomotive which provides the compressed air, must create a reservoir of air for the automatic brake. This also must be done as uniformly as possible throughout the various vehicles of the train. As a result release is even slower than application.

However, a quick release can be obtained, if desired, by the use of direct release brakes. The result is an " exhaustible " brake, the use of which can only be permitted on level lines. The device for operating it on heavy gradients, which consists in delaying the release, is only a palliative and produces unreliable results (either exhaustion or overcharging). Moreover, in order that the reservoirs shall be completely and reliably refilled after each release action, one must have recourse to a special method of operating the brake which consists of successive applications and releases and which leads to serious variations in speed. For this reason, it is better to rely on a brake which can be controlled

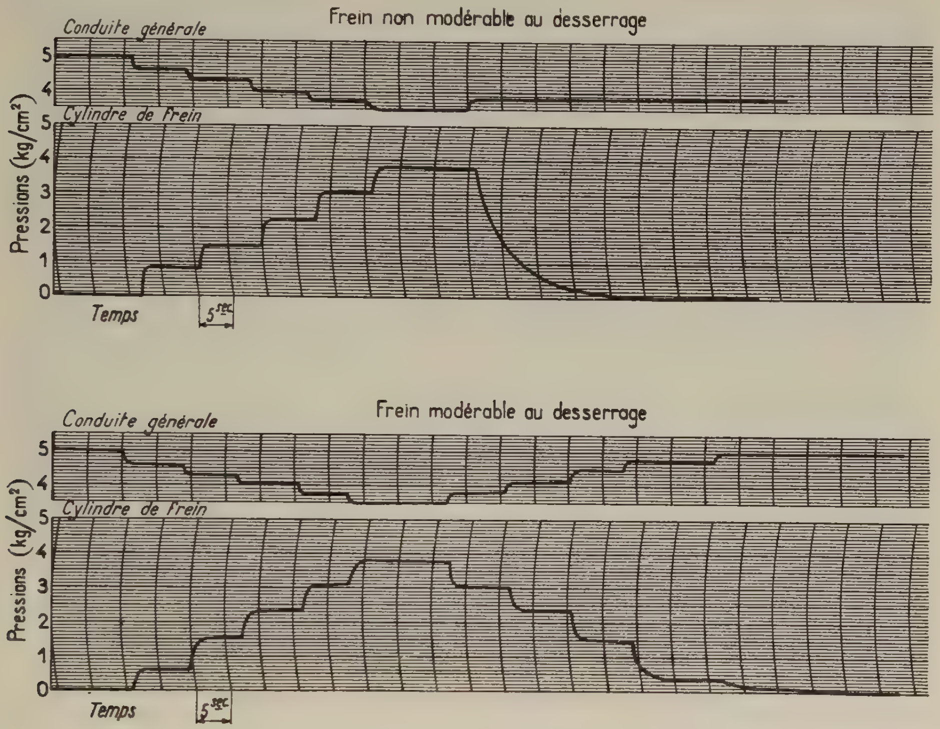


Fig. 5. — Graph of application and release of brakes which can and which cannot be controlled on release (CG and CF).

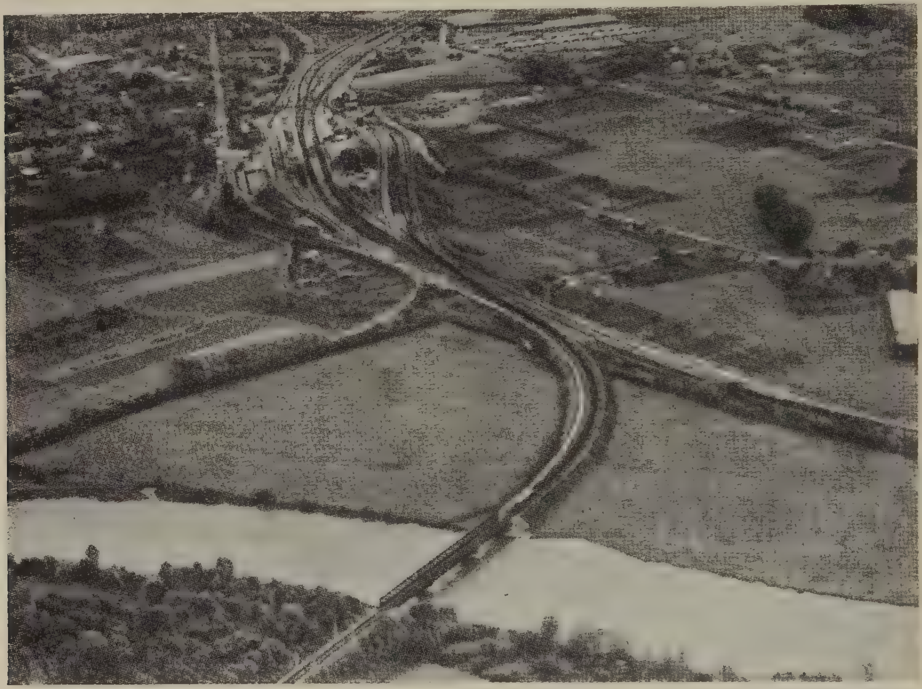
*Explanation of French terms :*

Frein non modérable au desserrage = brake which cannot be controlled on release. — Frein modérable au desserrage = brake which can be controlled on release. — Conduite générale = brake pipe. — Cylindre de frein = brake cylinder. — Temps = time. — Pressions (kg/cm²) = pressure (kg per sq. cm).

on release and which has the further advantage of being genuinely inexhaustible. (*N. B.* : There is a relationship between the pressure in the brake cylinder and that in the brake pipe during the time of release. As the pressure in the auxiliary reservoir does not influence this relationship, it can be connected to the brake pipe by a check valve and it will be replenished as the brake is released, so that inexhaustibility is assured.)

Finally, the concept of controllability is linked more than anything else with that of inexhaustibility. This does not improve the *ease* of control, however. This is not a serious disadvantage when going down steeply graded lines, for then there is no need to release the brakes completely in order to cease, so far as may be required, to slow down. On the level, on the other hand, drivers are well aware that a brake, which can be controlled on release, releases more slowly than a direct release brake (particularly in the case of passenger trains). For example, in order to decelerate quickly from a high speed, it becomes necessary, to a considerable extent, to prejudge the proper time for release, in order to avoid reducing speed considerably further than intended or even stalling. This disadvantage is the more considerable, the longer the train is.

Thus ease of operation is a most important attribute from the point of view of the



A test train of 200 axles, with Westinghouse controlled-release brake, entering the station fan at Montereau from the direction of Melun via Héricy; dynamometer car No. 1 has just crossed the viaduct over the Seine; the head of the train is already in the Montereau " fan "; to the left of the northern approach to Montereau, the famous Montereau " all-relay " signal box can be seen. (Photo provided by Westinghouse Company).

brake's users who are, in the last resort, the most concerned with its properties. However, no quantitive requirements in this regard are laid down in the conditions to be fulfilled. There may perhaps be a gap here which it would be worth while to fill.

Certain improvements in locomotive brake equipment enable the difficulties which have been mentioned to be alleviated to some extent. These will be considered before the distributors themselves are described.

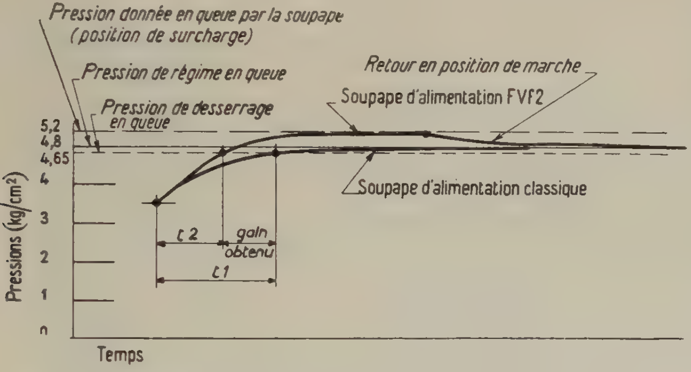


Fig. 6. — Diagram illustrating the improvement in release time achieved by an FVf2 supply valve.

*Explanation of French terms :*

Pression donnée en queue par la soupape (position de surcharge) = pressure produced at the rear by the valve in the overcharge position. — Pression de régime en queue = service pressure at rear. — Pression de desserrage en queue = release pressure at rear. — Retour en position de marche = return to running position. — Soupape d'alimentation FVf2 = supply valve FVf2. — Soupape d'alimentation classique = traditional supply valve. — Gain obtenu = improvement achieved. — Pressions (kg/cm ) = pressure (kg/cm$^2$). — Temps = time.

### Improvements in locomotive brake equipment.

So far as motive power is concerned the first essential is to obtain a supply of air at a suitable pressure. Consequently, it is noticeable that the output of compressors is increasing. An output of 3 000 litres/min. is now the minimum for a powerful locomotive. The compression pressure in the main reservoir must be at least 9 kg/cm$^2$ and the capacity of the reservoir itself must be sufficient to provide the supply of air which is vitally required at the moment of release.

But it is not sufficient for the equipment producing the compressed air to be capable of high output. It is essential that this air should reach the end of long trains at a sufficiently high pressure. The distributors return to the charging position at about 0.150 kg/cm$^2$ below operational pressure, and this small margin cannot be increased without impairing the inexhaustibility of the brake.

This leads to release being slow on occasion and even, sometimes, impossible. Consider, for example, the case of a train which has to reverse in a station. While the train is being hauled by the first locomotive there is, when the inevitable leakages are taken into account, a gradation of pressure from the head of the train to the rear, the head being at about 5 kg/cm$^2$ and the rear at about 4.800 kg/cm$^2$. When the second locomotive takes the train over, it produces a different state of affairs in the brake pipe. What was formerly the rear (with a pressure of 4.800 kg/cm$^2$) becomes the head (with a pressure of 5 kg/cm$^2$). The distributors at the head of the train release the brakes, but those which are now at the rear, which were charged at 5 kg/cm$^2$ must receive air at at least 4.850 kg/cm$^2$ to return to the charging position. If the second locomotive can only build up 4.800 kg/cm$^2$ at the tail end, the brakes will not be released. This awkward state of affairs can be remedied by moving the feed valve of the driver's brake to and fro in such a way that the pressure in the system is raised somewhat. This is frequently done abroad, but in France it has, for quite separate reasons, been forbidden and valve control systems are sealed. A more rational solution lies in the use of what are called " overcharge reducing " supply valves. Such valves allow the pressure in the system to be raised to about 5.400 kg/cm$^2$ instead of 5, with the driver's valve in a certain position (second, for example). On changing to the running position (the third position of the valve) overcharging is automatically eliminated and the pressure returns to 5 kg/cm$^2$ at a sufficiently slow rate for the distributors not to apply the brakes.

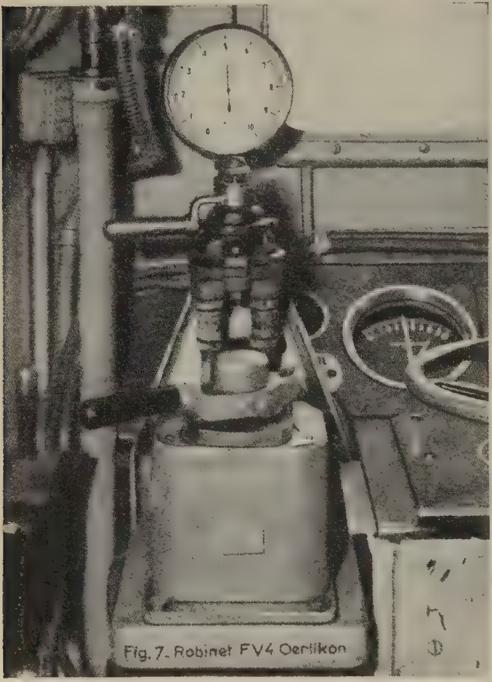


Fig. 7.

These valves allow for a quicker release in all circumstances, as is shown in figure 6.

The driver's valves have also developed. In the new types of brake the existence of a relationship between the pressure in the brake cylinder and that in the brake pipe during application as well as during release, naturally led to the idea of what is called the " manometric " valve, the operating handle of which acts on the control spring of an escape valve. There is a particular pressure in the brake pipe corresponding to each position of this handle. Such valves often include an overcharge release device which acts automatically in the same way as the supply valve already referred to. Certain valves even include a refill position (the first position) which restores the direct link between the main reservoir on the locomotive and the brake pipe only for a limited period, the length of which depends on the extent of the braking previously carried out. This avoids overcharging the brake gear at the head of the train while, at the same time, ensuring the maximum supply of air. Figure 7 shows a valve of this type which is at present being tried out.

In short, the use of precise air gauges is both necessary and convenient, in that it greatly increases the ease of operation of the brake. In addition to the gauge showing the pressure in the operating reservoir of the driver's valve, there must always be another, easily visible gauge showing directly the pressure in the brake pipe.

## MODERN TYPES OF DISTRIBUTOR

Included under this title are the distributors put on the market since the end of the last war. At present they are five in number : Charmilles, Oerlikon (Switzerland), Knorr type KE (Germany), Dako (Czechoslovakia) and Westinghouse E 2 (France).

### Technical details of new distributors with controlled release.

The old distributors, of which the triple valve, well known to readers of this article, is the most common in France, had as their main component a slide valve moving over a seating, pierced by holes as required. The slide is drawn by a piston equipped with a metal segment which moves in a casing. It will be appreciated that the movement of an assembly such as this leads to serious friction, which blunts the sensitivity of the triple valve. Herein is to be found one of the main reasons for the low speed of transmission achieved by distributors of this kind — a speed which, under the most favourable conditions, is about 130 to 150 m/s. This speed of transmission is insufficient for present day operating requirements, particularly when, as is frequently the case on the S.N.C.F., there are very long passenger trains with a high percentage of weight to be braked. In these circumstances it becomes difficult for even a skilful driver to avoid rough handling when braking under certain conditions, such as during controlled stops.

Test train (150 axles) going down the 32 $^{0}/_{00}$ gradient from Modane in the direction of Saint-Michel de Maurienne. At the rear, dynamometer car No. 1. (Photo S.N.C.F.)

In modern distributors the pistons are replaced by flexible diaphragms of synthetic rubber, which move only slightly and control valves of hardened rubber instead of slide valves. This method of construction ensures very great sensitivity and, thereby, a high speed of transmission. All modern distributors attain a speed of 250 m/s, which is now required by international regulation, and certain of them exceed this rate quite considerably (270 to 280 m/s). It is to be noted, however, that the most recent type of the Westinghouse (E 2) distributor has recourse to distributing parts with cylindrical slides for certain operations.

Moreover, in the new types of apparatus, certain of the operations which are termed secondary (though this does not mean that they are unimportant — quite the contrary) are carried out by distinct and, to some extent, specialised parts, while in the triple valve they were linked directly to the action of the main component of the distributor. In consequence, the results achieved are much more precise.

Finally, a substantial reduction in maintenance costs may be reckoned on as a result of this technique. Maintenance is reduced to the replacement of parts which are found to be worn, without the need for running in, or for precise adjustment, such as was required for triple valves.

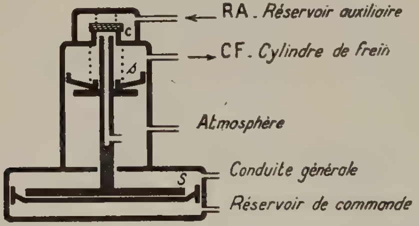


Fig. 8. — Diagram of main control member of modern distributors.

*Explanation of French terms :*

Réservoir auxiliaire = auxiliary reservoir. — Cylindre de frein = brake cylinder. — Atmosphère = atmosphere. — Conduite générale = brake pipe. — Réservoir de commande = control reservoir.

### Operation of the main control member of the new distributors.

All these distributors include a main control member which regulates the level of the air pressure admitted to the brake cylinder on application as well as on release. It is based on the well known " three pressure " principle and it is put in motion in the following way (fig. 8) : a hollow tube is affixed to two elastic diaphragms, S and s. The tube is able to raise a flat valve *c* which has two concentric openings. The inner opening exactly fits the hollow tube already mentioned and the outer opening fits over a seating which is fixed to a non-moving part of the distributor. The space surrounding the outer opening of the valve connects with the auxiliary reservoir. The space between the outer and inner openings connects with the brake cylinder. Finally, the hollow inside the tube connects with the atmosphere.

Further, the diaphragm S is subject, on its upper side, to the pressure from a small reservoir called the control reservoir which is filled to operational pressure during the charging of the brake and remains permanently at that pressure (or very near it) throughout the various stages of operation. The diaphragm *s* receives on its upper surface the pressure from the brake cylinder.

The way in which this control member works is easy to understand. In the " brake released " position, the two diaphragm assembly is in the lower position where it is held by a release spring. The valve *c* lies on its outer seating; the hollow tube does not touch the inner opening; the brake cylinder is at atmospheric pressure. When the brake is applied, the fall in pressure in the brake pipe causes the assembly to rise, as a result of the pressure obtaining in the control reservoir. The hollow tube touches the valve *c*, thus breaking the connection between the brake cylinder and the atmosphere, and then raises the valve. Air from the auxiliary reservoir then enters the brake cylinder. When the pressure in the cylinder, which is the same as the pressure above the diaphragm *s*, reaches a certain point, the moving assembly falls so that the valve *c* breaks the connection between the auxiliary reservoir and the brake cylinder, without reducing the pressure in the latter to that of the atmosphere (otherwise equilibrium would again be upset, this time in the opposite direction). A fresh fall in pressure in the brake pipe leads in the same way to a specific increase in pressure in the brake cylinder, and so on up to maximum brake application. The corresponding sequence of events takes place, obviously, when the brakes are released, through successive increases in pressure in the brake pipe. Ignoring the effects of the release springs and of friction, it can be seen that any alteration of pressure $\Delta p$ in the brake pipe is converted into a variation of pressure $\Delta p'$ in the opposite direction in the brake cylinder which is equal, in absolute terms, to the former multiplied by the ratio $S/s$. The brake can thus be controlled on release as well as on application.

It can also be seen that the control member has the effect of maintaining at a constant level the pressure in the brake cylinder, when this is subject to leakage This compensation takes place at the expense of the auxiliary reservoir which is fed from the brake pipe. This compensation for leakage is an important factor in achieving inexhaustibility.

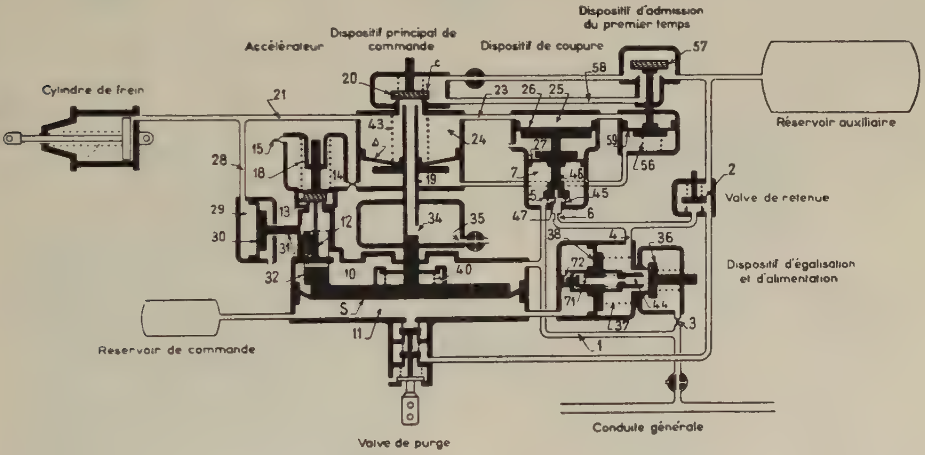


Fig. 9. — Diagram of Oerlikon Est 3 d distributor.

*Explanation of French terms :*

Cylindre de frein = brake cylinder. — Accélérateur = accelerator. — Dispositif principal de commande = main control member. — Dispositif de coupure = sealing valve. — Dispositif d'admission du premier temps = initial admission valve. — Réservoir auxiliaire = auxiliary reservoir. — Valve de retenue = check valve. — Dispositif d'égalisation et d'alimentation = equalising and filling valve. — Réservoir de commande = control reservoir. — Valve de purge = releaser. — Conduite générale = brake pipe.

## The " secondary " functions.

## The various phases of operation.

Let us now examine the action of the distributor as a whole. Let us consider it in the charged position, that is to say with the brake chambers filled to service pressure and with the brake off. Let us see what happens during the cycle of operations comprising an application, then a release, then a return to the charged position.

When a fall of pressure occurs in the brake pipe, a component called the accelerator links a chamber called the accelerator chamber with the brake pipe. This chamber, which was previously at atmospheric pressure, withdraws a certain amount of air from the pipe and thus enables the fall in pressure to be renewed from one vehicle to the next instead of dying out. The chamber may be open and be connected to the atmosphere by a calibrated opening. In that case it empties quickly. It may also be shut, in which case it empties towards the end of the release of the brake.

As soon as the distributor comes into action another device breaks the connection between the brake pipe, the pressure in which is falling, and the control reservoir, the pressure in which must remain constantly equal to the working pressure. The main control member, after isolating the brake cylinder from the atmosphere, sets air in motion from the auxiliary reservoir to the brake cylinder. If it is a freight wagon distributor, this influx of air occurs in two stages. An " initial admission " valve admits air rapidly at first, up to a pressure of 0.5 to 0.6 kg/cm$^2$ in the brake cylinder and then, after operation has started, more slowly, reaching the maximum amount in the case of a " full application " in a number of seconds equal to the " application time ".

head of a train when the driver's valve is in the first position). This prevents the auxiliary reservoir from being overcharged and allows the compressed air in the pipe to feed the rear vehicles in the train more quickly.

At the same time, the main control member sets the brake cylinder to atmospheric pressure.

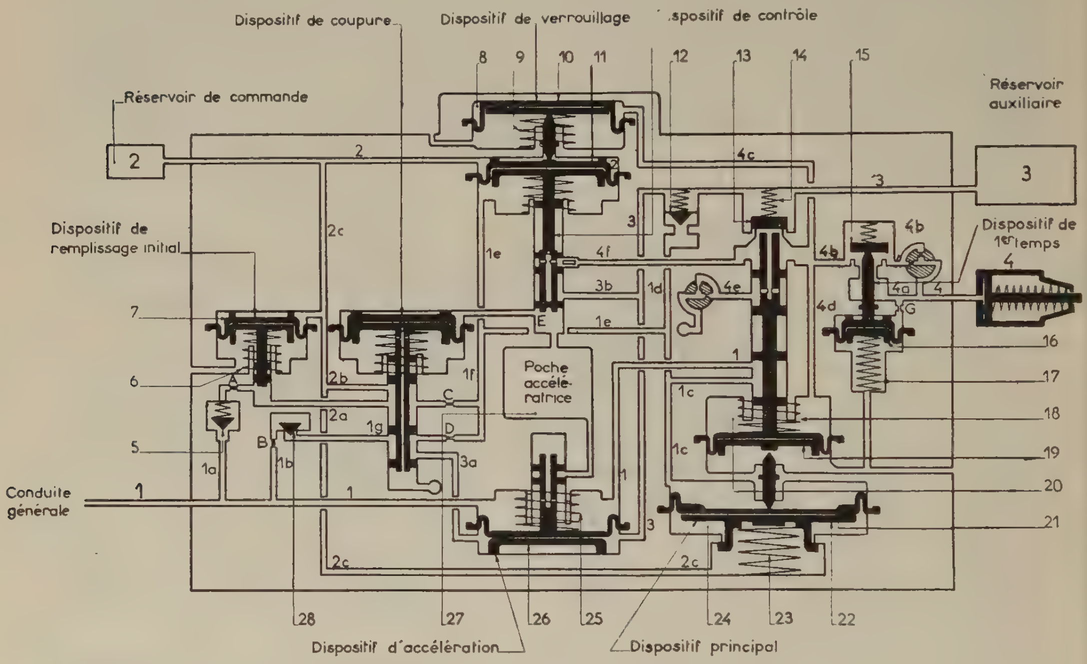


Fig. 10. — Diagram of Westinghouse E 2 distributor.

*Explanation of French terms :*

Réservoir de commande = control reservoir. — Dispositif de coupure = sealing valve. — Dispositif de verrouillage = locking member. — Dispositif de contrôle = control valve. — Dispositif de premier temps = first stage valve. — Dispositif principal = main control member. — Dispositif d'accélération = accelerator valve. — Dispositif de remplissage initial = initial filling valve. — Réservoir auxiliaire = auxiliary reservoir. — Poche accélératrice = accelerator chamber. — Conduite générale = brake pipe.

In order to release the brake a rise in pressure in the brake pipe is brought about. When the pressure therein is greater than that in the auxiliary reservoir, the latter is fed through the check valve. The distributor generally includes a device for regulating this feed, the effect of which is to slow it down when the pressure in the brake pipe is high (for example at the

Towards the end of the release, the accelerator is recharged and the accelerator chamber is emptied if necessary. Then the brake returns to the charge position when the pressure in the brake pipe is 0.150 kg/cm$^2$ lower than the working pressure. This last stage of the operation

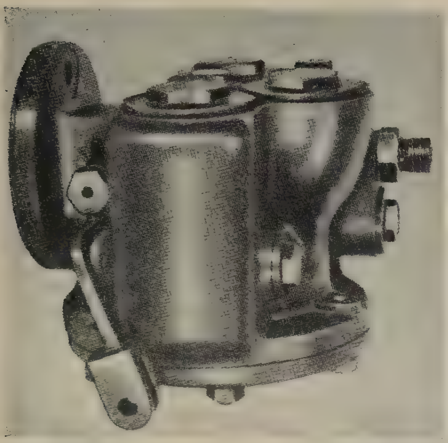


Fig. 9 (*a*). — Photograph of Oerlikon Est 3 d distributor.

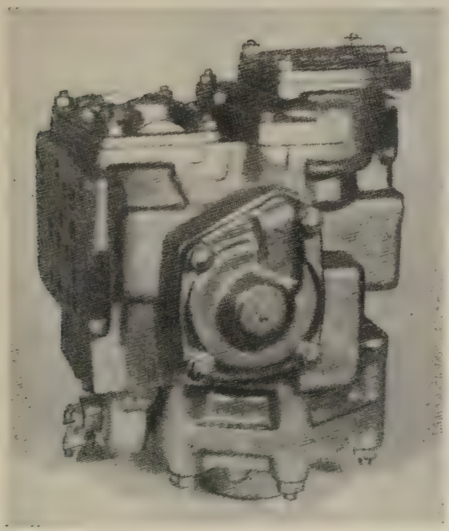


Fig. 10 (*a*). — Photograph of Westinghouse E 2 distributor.

is the most difficult. At this point, the brake pipe is, in fact, reconnected with the control reservoir. The latter, which has remained at the working pressure, tends to loose a little pressure. If circumstances require a new application of the brake at once, the pressure in the control reservoir at the beginning of the application is slightly lower than the initial working pressure. For a given pressure in the brake pipe the pressure in the brake cylinder will then be lower than on the first occasion. This situation may be repeated if the brake is clumsily operated. Most modern distributors are equipped to guard against incidents of this kind (which, in any case, can only exceptionally lead to serious exhaustion of the brake). The main danger arises from the fact that they normally only occur on some of the vehicles in a train. As a result, on a falling gradient, the braking force is irregular and is largely concentrated on the vehicles not affected. This may lead to overheating of the linings. Moreover, in addition to the positive protective measures taken, footplate staff are specifically instructed not to operate the brake when the pressure in the brake pipe is approaching the recharging pressure. At this point the brake must be positively

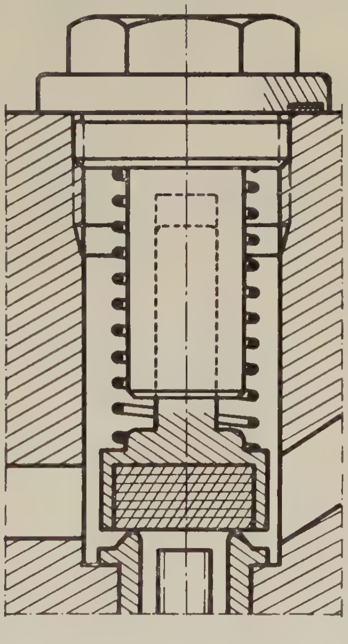


Fig. 11. — Type of valve used in the Oerlikon distributor.

and completely released so that all the chambers are recharged to working pressure.

Moreover, the distributor must also be protected against overcharging during the period of release when long applications have been made in the first position of the driver's valve. It must also be able to withstand an application in the first position at least two seconds long ( a requirement of the I.U.R. leaflets) when the brake has been fully released. In this position, the distributor is more easily affected by overcharging since the control reservoir and the auxiliary reservoir are linked with the brake pipe by chokes. But a short " touch of first position " is almost an instinctive action on the part of a driver, when a start proves to be difficult.

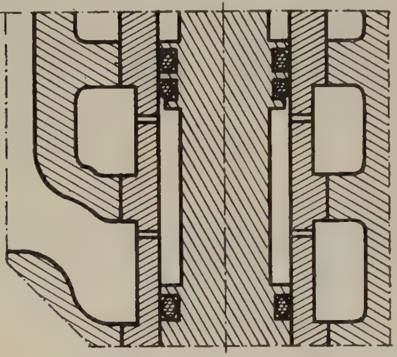


Fig. 12. — Cylindrical slide valve with R joints, used in Westinghouse distributor.

Modern, sensitive distributors would give rise to reapplications of the brakes at the time when the valve is returned to the second position, if they were not specially protected against these first position applicarions.

## Methods by which secondary functions are carried out.

We will now consider how all the conditions quoted above are fulfilled efficiently, by considering in greater detail the Oerlikon type Est 3 d distributor (now built in France under licence) and the Westinghouse E 2, diagrams of which are given in figures 9 and 10.

The S.N.C.F. has some experience of these two types, and particularly of the first. The second has only recently (October 1955) been officially submitted to the International Railway Union (I.R.U.). The S.N.C.F. has also carried out prolonged tests on a small number of " Charmilles " distributors.

It is first to be observed that the principles employed in opening and closing connections, apart from the principal admission valve of the main control member, are different in the two types of distributor.

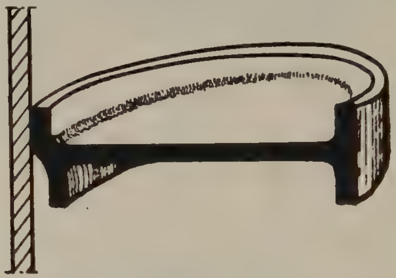


Fig. 13. — Oerlikon diaphragm.

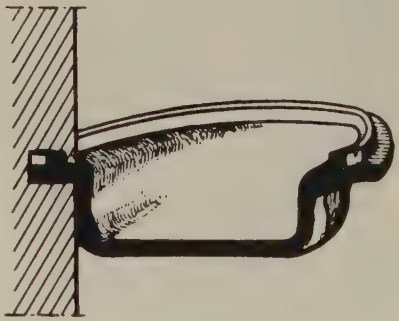


Fig. 14. — Westinghouse diaphragm.

In the Oerlikon distributor, the connections referred to are effected by valves consisting of a metallic mounting into which is vulcanised a rubber lining, which ensures that the joint is air tight (fig. 11).

The Westinghouse distributor has recourse almost exclusively to cylindrical slide valves made airtight by toric joints of synthetic rubber called " R joints " which move in relation to circular holes drilled in the sides of a sheath. The sheaths are made of stainless steel and their inside surfaces have to be very finely finished to reduce both friction and wear to a minimum (fig. 12).

The diaphragms also differ in concept. In the Oerlikon distributor, they are " H "-sectioned and not very thick. They are automatically rendered airtight by the pressure of the air on the vertical lips. This is an original and logical concept. In the E 2 distributor, they include a pad on which two metal parts grip each other, so as to make the joint airtight. Their shape reveals a marked fold. Figures 13 and 14 show these diaphragms diagrammatically.

The different stages of operation are carried out in the following manner :

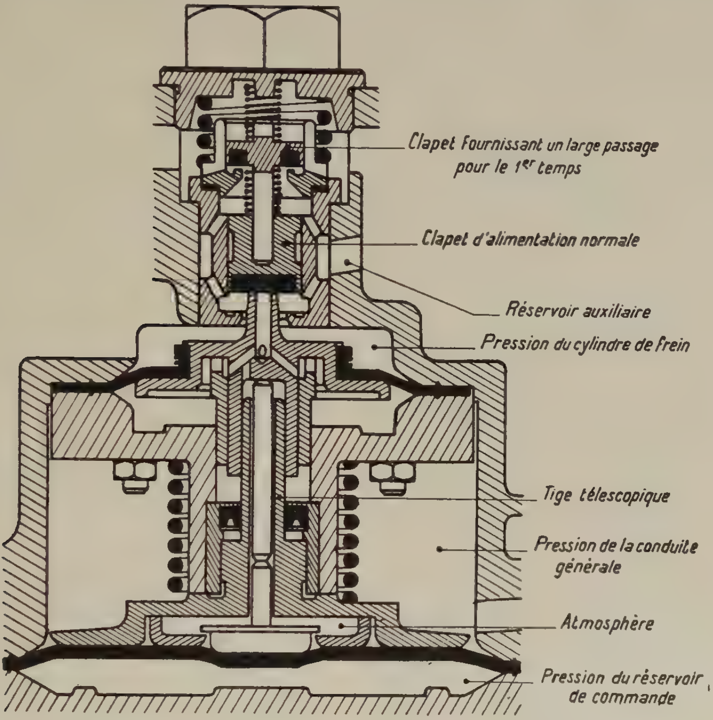

Clapet fournissant un large passage pour le 1er temps
Clapet d'alimentation normale
Réservoir auxiliaire
Pression du cylindre de frein
Tige télescopique
Pression de la conduite générale
Atmosphère
Pression du réservoir de commande

Fig. 15. — Initial admission of the Dako distributor.

*Explanation of French terms :*

Clapet fournissant un large passage pour le 1$^{er}$ temps = valve providing large opening for initial admission. — Clapet d'alimentation normale = normal feed valve. — Réservoir auxiliaire = auxiliary reservoir. — Pression du cylindre de frein = brake cylinder pressure. — Tige télescopique = telescopic tube. — Pression de la conduite générale = brake pipe pressure. — Atmosphère = atmosphere. — Pression du réservoir de commande = control reservoir pressure.

**Acceleration.**

In the Oerlikon distributor, the acceleration valve is controlled mechanically by the movement of the main control member at the start of the application. The valve is raised by a rocker arm which falls back immediately afterwards. A certain amount of air escapes through the valve into the accelerator chamber. The accelerator chamber then empties into the atmosphere through a choke. The pressure in the brake cylinder, acting on the diaphragm (30) of a locking member, holds the guiding face (32) in the high position. The accelerator cannot come into action during subsequent applications and releases. The locking device releases the rocker arm face towards the end of the release process (at a pressure in the cylinder of about 0.150 kg/cm$^2$). A notch inserted in the vertical section of the rocker arm can engage with the pipe of the accelerator valve before the main control member has fully returned to the lower position. It is thus possible to obtain acceleration when braking is resumed even whilst the pressure in the brake cylinder is low. This makes for greater ease of handling at low pressures. It is not always desirable for this acceleration to come into play too quickly during release, since the brake would then act too sharply during operations which are intended to be gradual. This is a compromise which has to be made, and which is made more or less successfully according to the different types of brake. This detail further illustrates how delicate the release operation is in its final stages.

In the Westinghouse distributor the accelerator apparatus consists of a diaphragm piston (26) receiving air from the train pipe above and air from the auxiliary reservoir below (and not from the control reservoir as in most other distributors). The piston moves a cylindrical slide R joints which connects the train pipe with the accelerator chamber. For a short space of time the accelerator chamber is connected with the brake cylinder, but as soon as the pressure in the latter, which receives air through the main control member, is high enough (0.200 kg/cm$^2$), it causes the locking member and the control member to fall and keeps them in the lower position. The control member cuts off the connection between the accelerator chamber and the brake cylinder.

During release, the accelerator apparatus returns to the first position as soon as the pressure in the train pipe becomes greater than that in the auxiliary reservoir, but the chamber is not emptied. It is only emptied when the pressure in the pipe reaches 4.750 kg/cm$^2$ and the pressure in the brake cylinder falls below 0.200 kg/cm$^2$. At that point, both the control and locking members rise again in such a way that the chamber is reconnected with the brake cylinder, which is itself in course of being emptied.

### Initial admission.

In most distributors, the arrival of air in the cylinder at the start of the application, which corresponds to the initial admission, is effected by two means, one being direct and the other through a choke. As soon as the pressure in the cylinder reaches a certain point (0.5 to 0.6 kg/cm$^2$) a valve controlled by a diaphragm closes the direct route. Now the air can only pass through the choke which is part of the freight passenger control valve. The air pressure then rises more slowly.

The apparatus is shown by numbers 57-58 on the Oerlikon diagram and numbers 15-16 on the Westinghouse.

The Oerlikon initial admission equipment includes a special feature of interest : compressed air from the accelerator chamber passes under the diaphragm of the member, thus slowing down the closing of the valve and producing a very pronounced initial admission. The effect is accentuated by the action of this same pressure which acts for a short time beneath the small diaphragm of the main control member thus accentuating the upward movement at the beginning of the application.

It is to be noted that, in the Dako distributor, there is an unusual type of initial admission equipment consisting of a telescopic system in the main control member which allows a valve to shut when the pressure in the cylinder has reached initial admission level (fig. 15).

### Isolation of reservoirs at time of braking. — Control of feed on release.

In the Oerlikon distributor, the control reservoir is isolated as soon as the pressure falls in the brake pipe, by an " equalising and filling valve " the piston of which (38) moves to the right under the influence of the pressure in the control reservoir. The hollow tube (44) touches the valve (36) and breaks the link between the control reservoir and the brake pipe. Moreover the raised valve (36) opens up a new path by which the air may pass to the auxiliary reservoir, whilst the normal route is blocked by the action of the sealing valve, the piston of which (26) impelled by the pressure in the brake cylinder, closes the valve (5). The new opening allows the feed from the auxiliary reservoir on release to be rapid, but controlled in relation to the pressure in the pipe. In practice, if the pressure in the brake pipe is high (front end vehicles) it tends to rise too much in the chambers (4). The valve (36) then reduces the supply of air to the auxiliary reservoir and thus steadies the feed to it.

Towards the end of the release the piston (36) returns to its seating, thereby breaking the connection between the auxiliary reservoir and the brake pipe, while the normal connection is resumed through the action of the valve (45), when the pressure in the brake cylinder has fallen to a level of about 0.200 kg/cm$^2$.

It is, however, to be noted that if the pressure in the pipe is still at this point markedly higher than that in the auxiliary reservoir (say by about 0.6 kg/cm$^2$), the valve (5) remains on its seating and the control tube which is assembled telescopically is separated from it. Air can only pass towards the auxiliary reservoir through a narrow opening in the valve. In this way, satisfactory protection is obtained against ultimate overcharging of the auxiliary reservoir.

The pressure has continued to increase on the righthand side of the diaphragm piston (38) and now reaches the level at which recharging of the brake should take place. Eventually, the hollow tube separates from the valve (36), linking the control reservoir with the passage which feeds the auxiliary reservoir (and thus, in effect, with the pipe) through the small opening (72) connected with the telescopic tube (71). The equalisation of pressure between the control reservoir and the pipe is very slow and the extent to which the control reservoir is emptied is thus limited. Then, as the difference between the pressure in the control reservoir and the pipe falls still further, the piston (38) is pushed fully to the left, the telescopic tube (71) sinks, thus uncovering the normal opening which is wider than the one referred to above and which connects the control reservoir and the brake pipe.

In the E 2 distributor the control reservoir is cutt off by the accelerator. It is thus cut off very quickly. The action is reinforced by the sealing valve which acts under the influence of the pressure in the brake cylinder. Shortly after, through the action of the control member the pressure in the auxiliary reservoir is substituted for that in the brake cylinder. This reinforcement is necessary since, as has been seen, the accelerating apparatus is able to return to normal position as soon, in the process of release, as the pressure of air in the brake pipe rises above that in the auxiliary reservoir. The cut-off apparatus also breaks the equalising link between brake pipe and auxiliary reservoir. As a consequence, the auxiliary reservoir is fed through the check-valve (12), the release spring of which sets up a difference of pressure of 0.120 kg/cm$^2$ between the brake pipe and auxiliary reservoir.

On release, the replenishment of the auxiliary reservoir is linked with the pressure in the brake cylinder through the action of the main control member, a logical state of affairs. In fact, when the pressure in the train pipe tends to exceed that at which the movable parts of the main control member are at rest, the latter fall and compress the spring (23). The link between 1 and 1*c* is broken and the pressure above the large diaphragm falls immediately, the moving parts rise again, and so on. Briefly, the main control member operates through the opening and shutting of the air inlet from the brake pipe in such a way as to maintain above the large diaphragm an air pressure which corresponds at all times to the air pressure in the brake cylinder. The pressure of the feed into the auxiliary reservoir is thus well regulated in relation to the air pressure in the brake cylinder.

At the end of the release process, when the pressure in the brake cylinder has fallen to 0.200 kg/cm$^2$, the locking member rises fully, releasing the control member which, at a pressure in the pipe of 4.750 kg/cm$^2$, also rises a certain distance and causes the accelerator chamber to empty into the brake cylinder and thence to the atmosphere. Then as pressure approaches 4.850 kg/cm$^2$, the control member rises the full distance, linking the piston of the sealing valve with the brake cylinder (instead of the auxiliary reservoir). The pressure in the brake cylinder continues to fall, the sealing valve rises again when the pressure has fallen to 0.100 kg/cm$^2$ and the normal link between the brake pipe and control and auxiliary reservoirs is re-established. The brake has returned to the charged position.

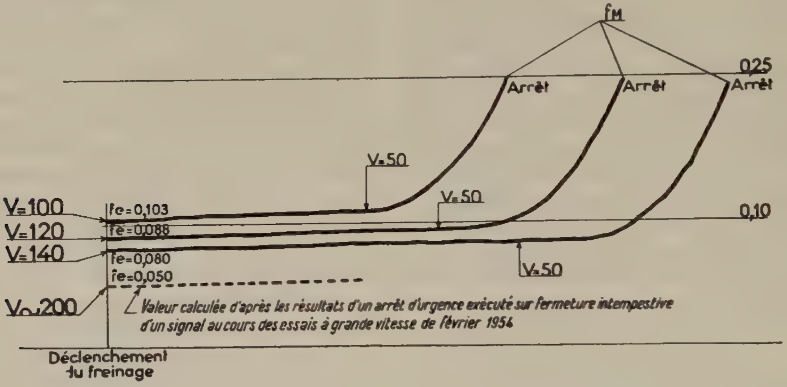


Fig. 16. — Variation in coefficient of friction of casting as a function of speed.

*Explanation of French terms :*

Arrêt = stop. — Déclenchement du freinage = brake release. — Valeur calculée suivant... = value calculated on results of an emergency stop carried out as a result of unexpected change to « stop » of a signal during high speed trials in February 1954.

### Protection against application of driver's valve in first position when the brake is released.

The specification of the I.U.R. leaflet requires an application of a least 2 s at 6 kg/cm$^2$. The brake should not be reapplied during the next 30 s.

In the Oerlikon distributor, protection is ensured by interlocking the auxiliary reservoir and the control reservoir. The size of the equalisation chokes is such that under all forseeable conditions the application is effectively absorbed.

In the E 2 distributor, it is the main control member that provides this protection. Excessive pressure in the pipe brings the main control member right down to the bottom position and compresses the spring (23). The passage of air from the pipe to the reservoirs is thus stopped and the overcharge can only flow through to the reservoirs slowly. As it does not last long, the required protection is ensured.

Thus all modern distributors have more or less complex provision for carrying out the various " secondary " functions. To describe them in detail would take too long. The principles employed in the five distributors put on the market in recent years have been summarised in tabular form. It is suggested that readers who want fuller information should consult the literature put out by the various makers.

### Results achieved by modern distributors.

The table of principal features of the Charmilles, Oerlikon Est 3 d, Knorr KE 1

| Features | Name of brake (passenger type) | | | | | |
|---|---|---|---|---|---|---|
| | Westing. Lu | Kunze. Knorr Kkp | Charmilles C2. B | Oerlikon ESt. 3d | Knorr K. E. 1 | Dako |
| **Reservoir refilling time** 0 to 4,8 kg/cm$^2$ control reservoir . . . . . | | | 163s | 155-165s | 86-99s | 180s |
| auxiliary reservoir . . . . | 87s | 100-140s | 82s | 155-165s | 80-88s | 180s |
| **Brake cylinder refilling time** to 0,95 of maximum pressure . . . . . . . | 3,4s | 7s | 5,2s | 4,5s | empty : 3,2s<br>charg. : 3,6s | empty : 3,5s<br>charg. : 4-6s |
| **Emptying time** of brake cylinder down to 0,4 kg/cm$^2$. . . . . . . . . . . . | 12-18s | 25s | 16s | 16-19s | 18,2-19,6s | 16-20s |
| **Reduction in pressure** required for complete application . . . . . . | 1,3-1,6 kg/cm$^2$ | 1,0-1,2 kg/cm$^2$ | 1,55 kg/cm$^2$ | 1,5-1,6 kg/cm$^2$ | 1,49-1,55 kg/cm$^2$ | 1,5-1,55 kg/cm$^2$ |
| **Maximum pressure** in cylinder . . . . . . | 3,4-3,7 kg/cm$^2$ | 4,100 kg/cm$^2$ | 3,9 kg/cm$^2$ | 3,7-3,9 kg/cm$^2$ | 3,45-3,5 kg/cm$^2$ | 3,7-3,9 kg/cm$^2$ |
| **Speed of transmission** in case of rapid application . . . . . . . . | 133-150 m/s | 166 m/s | 266 m/s | 275 m/s | 272 m/s | 269 m/s |
| **Sensitivity :** | | | | | | |
| **the brake is not applied** when the pressure falls by — Single vehicle . . | 0,450 kg/cm$^2$ in 60s | 0,400 kg/cm$^2$ in 60s | 0,300 kg/cm$^2$ in 34s | 0,520 kg/cm$^2$ in 60s | 0,590 kg/cm$^2$ in 60s | 0,450 kg/cm$^2$ in 60s |
| Train . . . . . | 0,165 kg/cm$^2$ in 60s | 1 kg/cm$^2$ in 8min. | 1 kg/cm$^2$ in 3min. 3s | 1 kg/cm$^2$ in 3min. | 1 kg/cm$^2$ in 4min. | 1 kg/cm$^2$ in 4min. 10s |
| **the brake is applied** — In the case of a single vehicle (when pressure falls by 0.6 kg/cm$^2$ in 6 s) in . . . . . . . . . . . . . | — | — | — | 0,5s | 0,46s | 0,55s |
| In the case of a train, when the pressure falls instantaneously by . . | 0,300 kg/cm$^2$ | 0,300 kg/cm$^2$ | 0,120 kg/cm$^2$ | 0,030 kg/cm$^2$ | 0,080 kg/cm$^2$ | 0,060 kg/cm$^2$ |
| **Refilling movement** after complete braking. (Length of time that 6 kg/cm$^2$ can be maintained in the pipe after complete application, without causing overcharge) . . . . . . . . . . . . | 10s | 20s | 15s | 30s | 13,5s | 41s |
| **Inexhaustibility** (Maximum percentage fall in brake power) . . . . . . . . . . . . . . . . | — | 30 % | — | < 5 % | 0 % | 1,14 % |
| **Refill application** when brake is released . . | — | — | — | 6s | — | 6,7s |

and Dako distributors has been reprinted, for information, from the I.U.R. leaflets. The Westinghouse E 2 distributor has not at the time of writing, finished its final official I.U.R. tests. It is possible, moreover, that it will undergo certain minor modifications which the first trials have shown to be worth while.

Also shown in the table are certain characteristics of old types of brake — one of them controllable on release : the German Kunze Knorr, the other non- controllable : the triple valve Lu. The progress achieved can thus be gauged.

In particular, the improvement in transmission time is striking. Inexhaustibility is almost total. Increased sensitivity allows for gradations in application or release, sometimes of the order of 0.050 kg/cm$^2$ at the brake cylinder. Protection against overcharging is excellent. These distributors are highly perfected. They represent, here and now, substantial progress, by comparison with the old equipment. There remains, in our opinion, another step to be taken to make brakes yet more easily handled on heavy trains. This will be referred to later.

## PRODUCTION OF BRAKING FORCE. HIGH POWER BRAKING

In the traditional types of brake, the retarding force is obtained by the friction of cast iron brake shoes on the steel tyres of the wheels. Such a method of braking does not achieve the shortest stopping distances when the force exerted at the shoe remains the same throughout the period of braking. In fact, the braking force must always be slightly less than the retarding force allowed by the adhesion of the wheel to the rail. This is expressed by the equation :

$$Q = P \frac{\Phi}{f} - \varepsilon$$

in which :

Q is the force with which the shoe is applied to the wheel, or the force at the shoe;

$f$ is the coefficient of friction of cast iron on steel;

$\Phi$ is the coefficient of adhesion of the wheel on the rail;

P is the weight imposed on the rail by the wheel.

In what follows, it will be assumed that P is constant, which is more or less the case with passenger rolling stock.

On the other hand, with freight wagons, P varies within wide limits, according to whether the wagon is loaded or empty. The brake equipment has to include loaded/unloaded equipment, which can either be discontinuous or continuous.

In the first case, the apparatus includes two (or three) braking systems, selected by means of a lever and the selection has to be carried out according to the particular weight on the rails of the wagon.

The continuous apparatus gives a braking power automatically related to the weight on the rails.

Both the discontinuous and the continuous apparatus may be operated mechanically or pneumatically. Most modern distributors can be equipped to provide braking related to the weight by pneumatic means. Certain types of passenger rolling stock in which the load may be an appreciable amount in relation to the tare weight (suburban rolling stock, railcars) are sometimes equipped with continuous load-adjusted braking apparatus.

It is known from recent experiments that, although adhesion depends to a great extent on the state of the rail, it varies little with speed, at any rate within certain limits. The same is not true of $f$. The calculation of this coefficient and of variations in it in relation to various parameters, has been the subject of many investigations over a number of years. Amongst the best known of them may be mentioned those made in 1878 by Douglas Galton, who carried out the first extensive experimental work on this subject. From this it was realised that the coefficient $f$ varies greatly with speed and, for example, in the course of braking from 100 km/h to a stop changes from 0.10 at 100 km/h to 0.25 towards the end of the stop. Much more recently, in about 1936, the O.C.E.M. carried out experiments under the guidance of Pedelucq, which made it possible to render the knowledge already acquired more accurate. Pedelucq's conclusions were as follows :

— During the whole of the descent of a gradient, carried out at constant speed, and with constant pressure at the shoes, the coefficient of friction ($f$) of the cast iron shoes on the tyres remains practically constant.

In the case of braking to a stop carried out with a constant pressure Q at the shoes, the coefficient of friction remains very nearly constant at a value $fe$, from the moment when braking is initiated to that when the vehicle's speed has fallen to about 50 km/h. It then rises sharply until the actual stop, at which point it reaches its maximum force $f$M.

— $fe$ depends both on the force at the shoe and on the initial speed; the *greater* the force at the shoe the *lower* is its value; the higher its initial speed the lower its value also — the graphs in figures 16 and 17 illustrate these results. These are empirical curves obtained with a given quality of cast iron. The numerical values may be somewhat different when the quality of the cast iron changes but essentially the laws remain true as formulated.

The results of these findings are clear. To avoid skidding with an ordinary brake, that is one which can only make a single application of maximum force at the shoe, the mechanism must be based on the highest value of $f$, which is to be found about the time of stopping. This means that much of the retarding power of the brake is lost at speeds over 50 km/h, since the limit of adhesion is not even approached. In practice, the vehicle's braking power cannot exceed $\lambda = 120\ \%$. If the efficiency of the brake equipment is to be increased, it must be designed in such a way that the force exerted at the shoe can vary, as the speed varies, more or less in inverse ratio to $f$ and, to carry matters to their logical conclusion, the force must also be related to the speed at the beginning of braking.

Such equipment has been made. It was complicated and its use in service was admittedly tricky. So, generally speaking, in recent years a simpler solution which provides for two degrees of force to be exerted at the shoe has been considered adequate. Firstly, there is a high speed stage and secondly a stage at under 50 km/h, with Q slightly lower than $\frac{P\Phi}{fM}$. With such equipment, values of $\lambda$ up to 160 % can be achieved, and this gives substantial improvements in stopping distances allowing, for example, operation at 160 km/h on lines signalled for 140 km/h (that is, for single stage brakes). If it is desired to exceed this and achieve $\lambda$'s of the order of 200 %, serious risks of skidding arise, which may have dangerous consequences (damaged tyres and serious increase in braking distance due to low value of the wheel/rail coefficient of friction). It then becomes essential to supplement the brake equipment with anti-skidding devices. Theoretically, there is no longer any need to have a brake with two or more degrees of pressure. The braking required to give retardation close to the limit of adhesion at high speed can be provided for and the anti-skid device can carry out the required lowering of pressure as speed or adhesion diminishes. In practice, things do not work out as well as this. When the limit of adhesion is approached, the anti-skid device operates frequently at the slightest momentary fall in adhesion. But despite the progress made in equipment of this kind, the increase in pressure after correction of skidding is not immediate. Each time the braking distance is increased. Moreover, the reserve of air provided is not inexhaustible and, after repeated correction of skidding, the amount of air used is such that the maximum pressure in the brake cylinder falls (unless very large capacity auxiliary reservoirs are provided — and this is not always possible).

Moreover experience has shown that there must be one anti-skid device for each axle, which makes this solution expensive, whilst, with a two-stage brake of medium capabilities, one set of equipment per coach is often sufficient. In a word, the maximum conceivable braking power, which applies the brake to very near the limit of adhesion, is not easy to use, and the results achieved with equipment which is designed to this end, so far vary too greatly for it to be possible to rely on what is, theoretically, the best performance in normal service.

In the present circumstances, it is thus both preferable and cheaper to have recourse to a two-stage brake without an anti-skidding device which gives a λ of 150 to 160 %. These are the limits permitted for the new class of coach recently specified by de I.U.R.

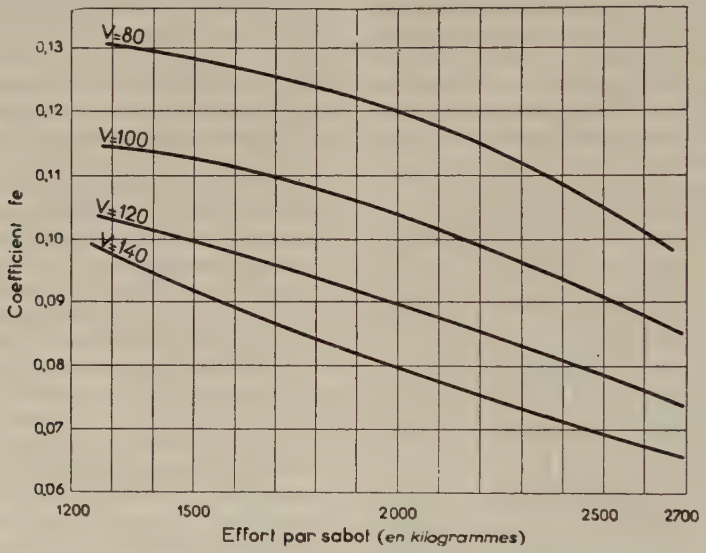
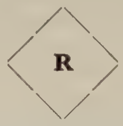


Fig. 17. — Variation of the cast-iron coefficient of friction in relation to the force at the shoe and the speed.

*Explanation of French terms :*
Coéfficient *fe* = coefficient *fe*. — Effort par sabot (en kilogrammes) = force per shoe (in kg).

These coaches carry the sign :



Further, since high speeds became common pratice, a limitation of a different kind has arisen and prevents the realisation of very high braking power. This limitation results from overheating of the shoes and especially of the tyres, which damages the latter. This leads to the concept of the maximum energy which can be dispersed per wheel in the course of a brake application. The length of the application plays an important part in determining the limit that is acceptable. It has already been established that this limit can be higher in the case of braking to a stop, when the power dispersed is, in any case, not constant, than in the case of a long and steep falling gradient such as that from Modane to Saint-Jean-de-Maurienne, for example. This is because the length of time during which the power is generated is shorter than in the first case. Repetition of braking at short intervals (as in suburban services) also lowers this limits. An interesting case in which this principle had to be taken into consideration was the question of the braking to be provided for the very high speed trials in March 1955. A series of preliminary tests enabled a limit of 70 kW to be dispersed by each wheel, to be fixed for the anticipated period of braking (four minutes). The " braking plan " to be carried out if a quick stop was required, was formulated on these postulates and allowed for a series of stages in braking. In this way, it was ensured both that there would be no damage to the wheels and that the brake shoes would not melt at an early stage, so leaving the train without brakes whilst still travelling at a very high speed.

This limitation also became apparent when an increase in locomotive braking power was sought. Generally speaking, locomotives are not so well braked as the vehicles they haul. Quite apart from steam locomotives, certain of which have very low λ's, the λ of a 2D2 is of the order of 0.65 and that of a CC 7100 of the order of 0.8. The latter figure is quite high and in the course of a full application at high speed, it involves a considerable dispersion of energy, since the axles involved are much more heavily loaded than coach axles. Moreover, in France at least, where high speeds are the normal rule, there is some hesitation about increasing locomotive braking power. During recent braking tests at 160 km/h, the locomotive used (CC 7116), which was equipped with a two-stage Oerlikon brake, had a λ of 102 % (compared with 150 to 160 % for the coaches).

The result of this state of affairs is that high speed trains must always include a certain minimum number of coaches, whose excess braking power can compensate for the locomotive's lack of such power in ensuring ability to stop within the distances required by the regulations.

Our knowledge of the limitations imposed by the power dispersed during braking is not yet very extensive. An experimental study of the question has been planned and is to be carried out. We cannot enter into the details of the tests proposed here, but will simply mention that the experiments necessarily include the measurement of surface temperatures of the tyres, for which new methods are being developed.

It is also to be hoped that, at the same time, research will be undertaken to improve the heat resistance of the tyres, for otherwise the traditional type of brake will quickly become unsuitable for the higher and higher speeds which may reasonably be expected in the future.

The high power brake systems recently tested on the S.N.C.F. will now be described.

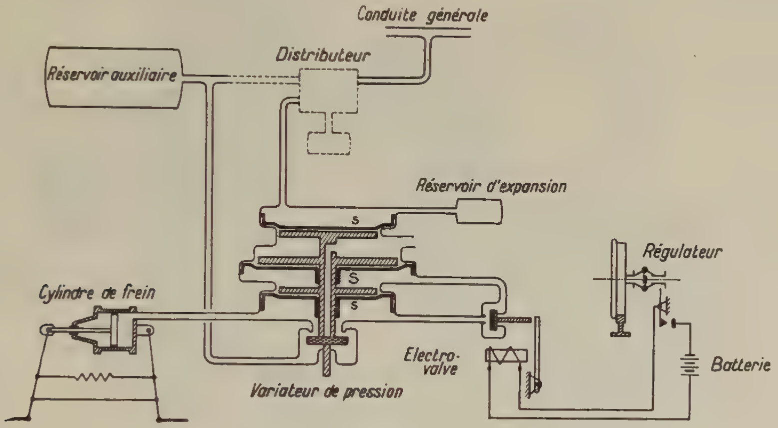


Fig. 18. — Diagram of two-stage Oerlikon brake.

*Explanation of French terms :*

Conduite générale = brake pipe. — Distributeur = distributor. — Réservoir auxiliaire = auxiliary reservoir. — Réservoir d'expansion = expansion reservoir. — Cylindre de frein = brake cylinder. — Variateur de pression = pressure regulator. — Electro-valve = electro-valve. — Régulateur = regulator. — Batterie = battery.

### Description of two-stage Oerlikon brake.

The diagram (fig. 18) shows a normal type of distributor, but this, instead of feeding the brake cylinder, feeds an additional chamber or false cylinder. A further device, which can vary the pressure, is designed to admit air to the brake cylinder, in proportion to the pressure obtaining in the false cylinder, at one of two different pressures, according to whether the speed is more or less than 50 km/h.

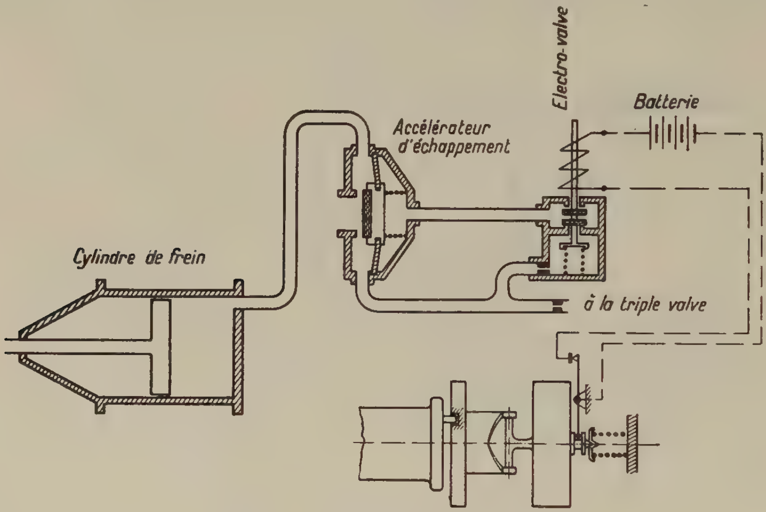


Fig. 19. — Diagram of the Jourdain-Monneret anti-skid brake.

*Explanation of French terms :*

Cylindre de frein = brake cylinder. — Accélérateur d'échappement = escape accelerator. — Electro-valve = electro-valve. — Batterie = battery. — à la triple valve = to the triple valve.

The pressure controller includes a valve with two ring seats controlled by a hollow pipe (similar to the main component of a distributor). The pipe is controlled by three diaphragm pistons. The top diaphragm of cross section *s*, is subject on its upper side to the pressure from the false cylinder, and on its lower side to atmospheric pressure. The middle membrane, the surface area of which is S, is subject to atmospheric pressure on its upper surface, and either to the brake cylinder pressure or to atmospheric pressure, on its lower surface, according to speed. The lower diaphragm of cross section *s*, is subject to the same pressure as the middle diaphragm on its top surface and the brake cylinder pressure on its lower surface.

The link between the chambers below these two diaphragms can be opened or shut by an electric valve which also connects S to the atmosphere when the link is shut. The electric valve is energised by a centrifugal regulator worked from an axle, when the speed exceeds 50 km/h and the link is shut. It is disenergised when speed is 50 km/h or less and the link is opened.

The method of operation is as follows :

If the speed is over 50 km/h, the chamber S is open to the atmosphere, and the controller thus creates the same pressure in the brake cylinder as in the false cylinder.

If the speed is equal to or less than 50 km/h the chamber S is at the brake cylinder pressure, and since the cross section S is greater than *s*, the moving assembly rises and links the brake cylinder to atmosphere, lowering the pressure therein until its ratio to that in the false cylinder (which has not changed) is $s/S$. In the most common type of apparatus this is roughly 1/2.

This equipment is being provided on the S.N.C.F. in a certain number of coaches now under construction. It is already in service on a few coaches on French railways.

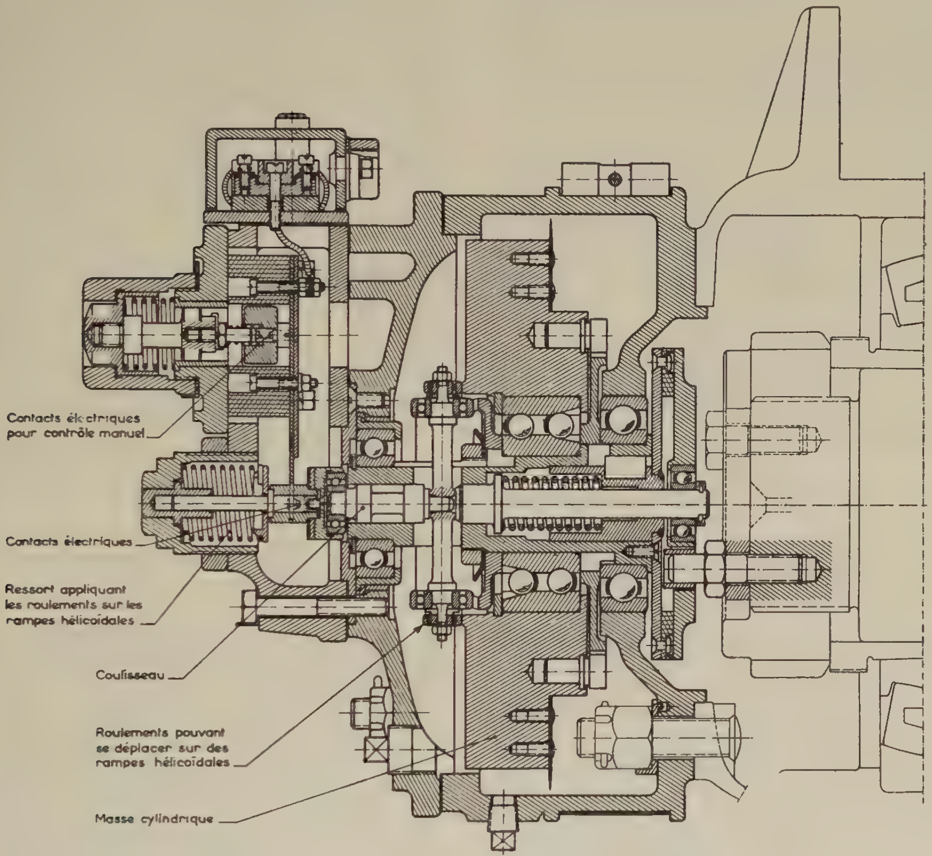

Contacts électriques pour contrôle manuel
Contacts électriques
Ressort appliquant les roulements sur les rampes hélicoïdales
Coulisseau
Roulements pouvant se déplacer sur des rampes hélicoïdales
Masse cylindrique

Fig. 20. — Jourdain-Monneret anti-skid device.

*Explanation of French terms :*

Contacts électriques pour contrôle manuel = electric contacts for manual control. — Contacts électriques = electric contacts. — Ressort appliquant les roulements sur les rampes hélicoïdales = spring holding bearings against the helical ramps. — Coulisseau = slide. — Roulements pouvant se déplacer sur les rampes hélicoïdales = bearings free to move on helical ramps. — Masse cylindrique = cylindrical block.

A preliminary series of tests with these coaches has already been carried out. It has proved possible to obtain a value for the coefficient $\varphi$ in the O.C.E.M. formula at a speed of 160 km/h, though this figure is provisional, because of the small number of tests so far carried out. This has enabled various problems to be solved and, in particular, it has enabled an examination to be made of the conditions under which operation at 160 km/h is possible on lines signalled for 140 km/h.

In the course of fly-shunt tests, this coache's $\lambda$ has been found to be 155 % under " R " operation, and 110 % in normal service. Locomotive CC 7116 which was used for these tests and which is also equipped with a two-stage brake has a $\lambda$ of 102 % under " R " conditions and 82 % in normal service.

Here are some figures recorded in the course of these tests.

With a train of six empty coaches, on the level, a stopping distance of 1 170 m was obtained from a speed of 160 km/h, 810 m from 140 km/h and 635 m from 120 km/h. These figures were obtained under the most favourable conditions. When the locomotive is braked under normal service conditions, the distance at 160 km/h is 1 280 m.

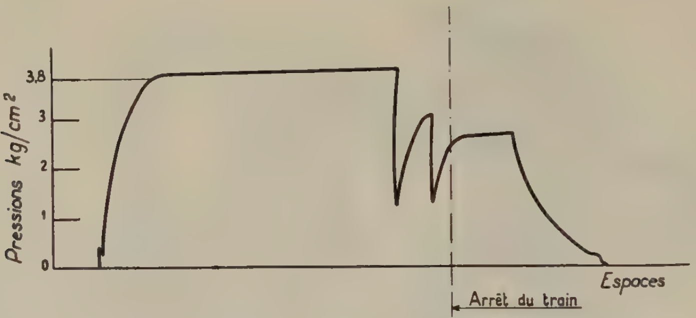


Fig. 21. — Diagram of pressure recorded during a test of the Jourdain-Monneret anti-skid brake.

*Explanation of French terms :*

Pressions kg/cm² = pressures in kg/cm². — Arrêt du train = stopping point of train. — Espaces (here) = time.

**Description of the Jourdain-Monneret anti-skid brake.**

A diagram showing the principles of this device is given in figure 19.

The brake equipment includes a distributor like that on an ordinary brake including a valve called the escape accelerator which allows the brake cylinder to be emptied rapidly if a pair of wheels should skid. The escape accelerator consists of a high capacity valve which can reduce the brake cylinder to atmospheric pressure. The valve is held to its seating by a spring and is controlled by a diaphragm subject on both sides to the brake cylinder pressure. The link between the two sides of the diaphragm can be cut by an electro-valve which, at the same time, reduces the side of the diaphragm opposite the escape to atmospheric pressure.

The mechanism which measures the axle's deceleration and causes the electro-valve to be energised is constructed as follows : a cylindrical block is mounted freely on a shaft turned by the axle. A slide turns with this shaft, the longitudinal movement of which controls the contact of the electro-valve. The slide is linked to an arm, at right angles to the shaft, on the ends of which are two small ball races (fig. 20). The races rest on a helical ridge which is part of the cylindrical block. The two parts, the slide with its arm and the block, are kept in contact by a spring.

When running at constant speed the assembly turns with the axle. When braking occurs, the slowing down of the axle causes the cylindrical block to shift in relation to the slide. The latter tends to move longitudinally, propelled by the helical ridge, and compresses the spring. If the deceleration exceeds a given amount, as happens when the pair of wheels has a tendency to skid, the movement causes the electro-valve circuit to close and the skid is corrected. Braking recommences when the wheel starts turning again and the block returns to its former position.

Tests carried out with this apparatus have shown that it works satisfactorily. Very good distances have been achieved on dry rails. For example, with a train consisting of six coaches and a CC, braking distances of 1 060 m at 160 km/h and less than 800 m at 140 km/h have been recorded. However, as has been stated, the performance of brakes based on this principle is subject to wide variation when they are applied up to near the limit of adhesion. The solution is also expensive since one anti-skid device is required for each pair of wheels. Figure 21 shows, by way of illustration a diagram of pressure recorded during the trials already quoted. The two corrections of skidding, which occurred towards the end of the stop, and which were followed by a renewal of pressure can be seen on it.

*N. B.* — It should be noted that these figures must not be compared with those quoted earlier for the two-stage brake. The conditions of the test (rolling stock characteristics and locomotive braking) were not the same. If a basis for comparison is sought, it may be said that, under similar conditions and with the appropriate alterations to the rolling stock under test, roughly the following results could be achieved :

900 m at 120 km/h, 1 200 m at 140 km/h with a one-stage brake.

650 m at 120 km/h, 950 m at 140 km/h with the two-stage brake.

600 m at 120 km/h, 800 m at 140 km/h, 1 100 m at 160 km/h with the anti-skid brake on dry rails.

It should be added that the manufacturers intend to improve the equipment which has been described by decreasing the time required to set it in motion and the consumption of air. The aim is to use it on the pendulum-suspension coach being designed for the S.N.C.F., for which this type of brake has been specified.

Finally, for the record, the decelerator brakes in which the deceleration measured is not that of the axle but that of the vehicle must be mentioned. Their control appears a priori to be more difficult than that of the brakes described above and they seem less reliable from the point of view of preventing skidding. They have been used outside France (a test has also been carried out on the Sceaux line) but the S.N.C.F. has not carried out any experiments with this type of brake.

### Use of brake shoes with constant braking coefficients.

There is a method of overcoming the consequences of the rise in the coefficient of friction of cast iron on steel towards the end of the process of stopping, by using materials which have a more or less constant coefficient of friction in relation to steel, whatever the speed. By this means very good braking performances may reasonably be expected from a brake which, being single stage, is simple and does not include mechanism which is connected with the wheels.

Moreover, as the coefficient of friction of such materials is high (in general of the order of 0.15 to 0.30), the strain on the brake gear is less than with the use of cast iron and, this being the case, it is possible to make the gear lighter.

Two forms of such materials have been tried out with success :

1) Composite cast iron/carbon linings. These linings consist of a layer of cast iron with sockets drilled in it, in which are fixed blocks of carbon.

2) Linings made of the type of material of which motor car brake equipment is made.

Tests have shown that promising results can be achieved with these linings but their use has not so far been developed for their cost is high and they wear quickly (either by actual wear or through insufficient mechanical resistance causing premature breakage). Moreover, it is not certain that they are harmless to the tyres, since heat is not dispersed in the same way as with cast iron linings. In fact, it has been established that heating of the tyres is more severe than with cast iron linings. Finally, and this has its disadvantages, at least on passenger trains, certain linings cause the emission of fumes and unpleasant smells during braking.

Apart from this, the use of materials with constant coefficients of friction requires the use of anti-skidding devices if very high $\lambda$'s are required. Thus the system becomes very expensive.

None the less, it is true that this field shows some promise and it would be worth while to carry out research aimed at removing the undeniable disadvantages.

It is also worth remembering that research has been carried out by the S.N.C.F. with the object of improving the quality of brake linings. This has led to the formulation of a specification for a type of cast iron called P 14 cast iron (which includes 1.4 % phosphorus). This cast iron has excellent wearing qualities. It can be seen that this is an important factor from the fact that 15 000 to 25 000 t of brake shoes and linings are used by the S.N.C.F. each year.

## DISC BRAKES

What may be called the traditional braking systems have now been reviewed — that is pneumatic brakes acting on the running surfaces of the wheels.

The disadvantages of this type of operation have been mentioned in the course of the review.

The search for a solution has proceeded for a long time. The drum brakes installed on certain railcars may be recalled. But this solution, which was inspired by the technique of the motor car industry, was ill adapted to railway rolling stock. The brakes were difficult to adjust and costly to maintain.

More recently, the use has been developed of brakes in which the braking takes place on discs which form part of the axles. This system has been applied in certain case in Germany and the U.S.A.

Disc brakes, in addition to the advantages which they offer in relieving tyres of the heating effects of braking, also, in general, enable simpler brake gear to be used than with shoe-brakes. Such gear makes less noise when in motion and the disc brake itself is more silent when in action than the traditional type of brake. As a result the standard of confort provided in the coaches is increased.

Against these advantages, it is clear that it is not always convenient, through lack of space, to mount the discs on the axles. On motored axles in particular, it is generally inevitable that the discs should be placed on the wheels, and this is sometimes difficult. The discs must be of the largest possible diameter, so as to effect the required braking couple with a low pressure on the linings. Moreover, large diameter discs cool better. Here too the dispersal of heat presents problems. The discs are double and include radial blades between the two faces and the openings in the latter are arranged to be near the hub. The ventilating effect thus obtained during rotation of the axle cools the discs. In addition to this the cooling is improved in so far as the discs can be placed so as to benefit as much as possible from the air movement caused by the speed of the vehicle. Therefore the discs must not be covered. If cooling is insufficient, the discs heat up excessively and may become deformed.

Disc brakes use linings made of special materials, which provide a coefficient of friction that is almost independent of speed. The behaviour of these linings in relation to heating and their resistance to wear are here of prime importance. It has not been finally established that the maximum dispersion of energy is much greater with the disc brake than with the traditional shoe brake, for the number of discs cannot be increased. Two at the most can be put on each axle. The application of the two types of brake on one vehicle has sometimes been considered. This arrangement answers the criticism sometimes directed at the disc brake that vehicles equipped with it tend to operate the track circuits imperfectly since the tyres are no longer cleaned by the friction of the shoes. However, it is clear that such an arrangement is both complicated and costly.

The installation of the disc brake is much more costly than that of the traditional brake. It remains to be decided whether

**Principles employed for « secondary functions » in the modern-type distributors of the five brakes considered.**

| | Charmilles | Oerlikon | Knorr K E | Dako | Westinghouse E 2 |
|---|---|---|---|---|---|
| Acceleration. | Valve operated by difference of pressure between CR and BP. Chamber closed. Exhaust effected by pressure in brake cylinder at end of release. | Valve operated mechanically by main control member, at beginning of its travel, by a rocker arm.<br>Control system secured by pressure in brake cylinder, after arm has raised valve and has then let it fall back after rocking movement. Chamber open. Reset during release (a little before CR is again linked with BP) | Valve operated directly by main control member — chamber open — BP / chamber link by valve operated by brake cylinder pressure.<br>Reset for use at end of release. | Valve operated by difference in pressure between BP and CR. Another valve allows some air to be taken from the BP and delivered to the brake cylinder till pressure has fallen by 0.4. Chamber closed, reopens during release through action of of special valve operated by pressure in brake cylinder. | Cylindrical slide with R joints operated by difference of pressure between BP and AR. Chamber closed, sending air to brake cylinder. This supply of air ceases on the operation of locking member controlled by pressure in the brake cylinder. On release, the cylindrical slide returns to original position when pressure in BP > in AR but chamber is only emptied if pressure in BP is > 4.750 with brake cylinder pressure lower than 0.200. |
| Initial admission. | Valve operated by given pressure in brake cylinder, causing change in opening through which air reaches brake cylinder. | Valve operated by given pressure in brake cylinder, causing change in opening through which air reaches brake cylinder. | Valve operated by given pressure in brake cylinder, causing change in opening through which air reaches brake cylinder. | Telescopic equipment in main control member allowing a valve to close when pressure in brake cylinder reaches initial admission level. Closure of this valve involves change of opening feeding the cylinder. | Valve operated by given pressure in brake cylinder, causing change in opening through which air reaches brake cylinder. |
| Cutt off (Isolation of containers at moment of braking) | CR / valve controlled by pressure in brake cylinder, which isolates CR and BP.<br>AR / check valve. | CR / by feed control apparatus (through difference in pressure between CR and BP)<br>AR / by valve operated by difference in pressure between BP and BC. Feed control valve opens second path to AR through check valve. | CR / valve operated by pressure in brake cylinder, which isolates CR and BP.<br>AR / check valve. | CR / valve controlled by pressure in brake cylinder.<br>AR / ditto<br>This valve breaks link between the two reservoirs and the BP. | CR / cylindrical slide operated by accelerator system (difference of pressure between BP and AR) secured by sealing valve operated by pressure in cylinder. Pressure of AR then substituted, by operation of control member. AR / by sealing valve (see above). |

Principles employed for « secondary functions » in the modern-type distributors of the five brakes considered (*continued*).

| | Charmilles | Oerlikon | Knorr KE | Dako | Westinghouse E 2 |
|---|---|---|---|---|---|
| **Control of feed and equalisation of pressure during release.** | BC emptied through main control member while AR is filled through check valve. CR reopened when pressure in brake cylinder falls below 0.200. Replenishment of AR slowed down towards the end of refilling by « refill control » valve. | Feed of AR operated by special appliance worked by difference in pressure between CR and AR. At the end of release, this passage closes and AR is fed through the sealing valve and through an opening of reduced size, if the pressure in the BP rises by 0,6 or more above the working pressure, whatever the pressure in the brake cylinder may be.<br>Connection with CR is opened by feed control mechanism at the end of release. A telescopic tube in this mechanism provides that only a small opening is available during a certain length of time. The loss of pressure in CR is thus reduced. When the difference of pressure between BP and CR tends to disappear, the normal aperture is opened, by the compression of the telescopic tube. | 3 pressure feed mechanism controlling admission of air to AR in relation to pressure in cylinder.<br>Opening of CR controlled by pressure in brake cylinder, at first through small aperture, then by normal aperture towards end of release. The fall of pressure in CR is thus reduced. | During release, AR is fed through « feed reverser » which reduces feed at the end of release. This protects AR against long first position applications. Normal links between BP and CR and AR are renewed at the end of release by the sealing valve when the pressure in the cylinder is low enough, but only if the pressure in the brake pipe is not more than the working pressure. | Feed is controlled by action of main control member which is depressed when the pressure in the BP rises too quickly and breaks the link between BP and AR (by means of a cylindrical slide with R joints). During release, pressure in AR acts first on sealing valve, which prevents it from rising too soon. At the end of release (pressure in pipe 4.850) the pressure level in the brake cylinder is substituted for that of the AR so far as the sealing valve is concerned (through the action of the control mechanism). As soon as the pressure in the brake cylinder is < 0.100 the sealing valve opens the link between the regulating and control reservoirs and the BP. |
| **Protection against first position application when brake released.** | Sealing valve shuts in event of rapid overcharging of BP.<br>Further protection provided by chokes. I.U.R. conditions observed. | No special mechanism, but AR locked with CR. Protection by normal chokes. I.U.R. conditions observed. | Reservoir fed by 2 apertures. One of them blocked by lower diaphragm of main control member in extreme lower position when pressure in BP exceeds working pressure. Very small aperture then remains allowing only very slow overcharge. I.U.R. conditions observed. | Equalising and sealing valve which shuts when pressure in BP is > than working pressure. | By action of main control member which is lowered and isolates BP from CR and AR feed. |

*AR* = *Auxiliary reservoir*
*CR* = *Control reservoir.*
*BC* = *Brake cylinder.*
*BP* = *Brake pipe.*

the balance is in favour of using it. This would require its maintenance cost to be markedly lower than that of the shoe brake, particularly in so far as the wear of the linings compared with that of cast iron shoes is concerned.

The S.N.C.F. has not so far carried out any trials with this type of brake on its rolling stock. A railcar now being built is to be equipped with it and tests on coaches are also planned. Figure 22 shows a diagram of the mounting of a disc brake on an axle.

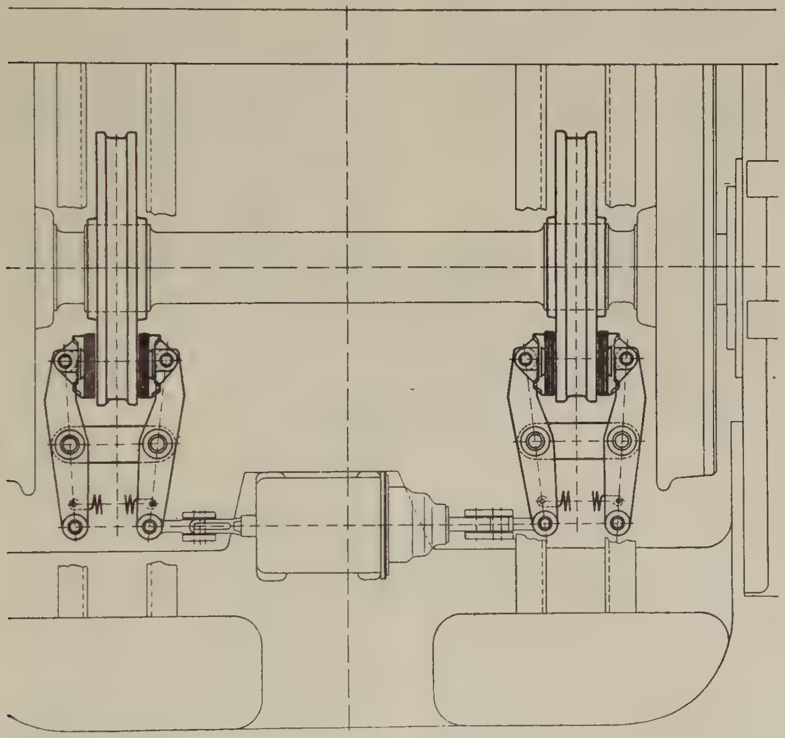


Fig. 22. — Diagram of mounting of disc brake.

## ELECTRICALLY CONTROLLED BRAKES

In what has been said so far, the part played by the distributors has been basic. Much is required of this component and it has become a real receiving instrument, reliable and exact, remotely controlled by orders sent from the locomotive through the medium of the driver's valve. Moreover, these receivers are strung out in large numbers all along a train which may be 800 m in length and all respond in almost exactly the same way to these orders. To quote such achievements at a time when robots of all kinds are being developed is not very startling. What is much more surprising is that this remote control operates solely through the medium of compressed air, through a pipe 25 mm in diameter. Moreover, it is this pipe also which transmits, in the form of compressed air, the energy which operates the brake. In this context, the results achieved appear remarkable. But are they, for all that, satisfactory? It is difficult to reply in the affirmative without hesitation. In particular, as has been seen, the operation of distributors, placed all along the train, is not simultaneous. The speed of transmission, about 250 m/s, makes it essential for the duration of the application to be several seconds at least. Release is slow. To sum up, the brake is still not very easy to operate.

The use of electricity to operate the brake thus seems to be indicated. The idea is not new. It has even been carried into effect, particularly during the last few years. If this method of control has not developed very quickly it is because it appears to be an additional complication, since compressed air, as a source of power, is particularly well adapted to the braking requirements of railway rolling stock. Up to the present, it has been considered adequate and pneumatic control is still in general use. But under present railway operating conditions, particularly on the S.N.C.F., the quick response of the brake that is a feature of electric control, is of increasing value. Besides, the recent movement in favour of automatic operation and the all-importance of speed can only logically be provided for by electric control.

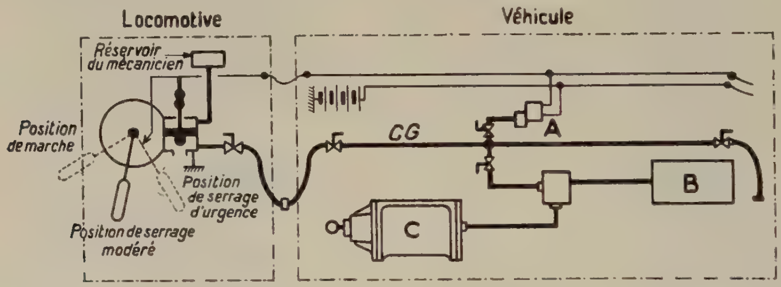


Fig. 23. — Diagram of brake with electrically controlled application only.

*Explanation of French terms :*

Véhicule = Vehicle. — Réservoir du mécanicien = driver's reservoir. — Position de marche = running position. — Position de serrage modéré = medium brake application position. — Position de serrage d'urgence = emergency brake application position. — A = electro-valve. — B = auxiliary reservoir. — C = cylinder.

It is not intended to describe the various solutions already known or those which may be conjectured. Even less is it proposed to forecast the choice that will eventually be made. The time is not yet ripe. But it should be recalled that in this type of problem the transitional period, which may be very long, must always be taken into account, and the possible use of old and new equipment in combination must be allowed for.

At the technical level, all electric control systems include, basically :

— On each vehicle :
an electric application valve and an electric release valve, a brake distributor with accessories, one or two brake pipes (it should not be forgotten that, in order to release the brakes quickly, the air must be conveyed to the rear of the train and this may require a second pipe), ducts and electrical connections from one vehicle to another.

— On the locomotive :
electric control equipment, which may or may not be subject to the pressure in the pipe, in addition to normal pneumatic controls and a source of electric current.

Starting from this basis, more or less simple schemes can be worked out, each with its own peculiarities. The choice between them depends on the importance to be attached to each of these peculiarities. Finally, the standard of construction of the electric and electro-pneumatic parts and their ability to withstand the heavy wear of railway service are factors quite as important as the system adopted. In short, the research and testing establishments concerned on the S.N.C.F. will have plenty of work in the years to come.

To conclude this subject, and to give an idea of some of the advantages to be expected from electric control, some results of tests recently carried out are given.

The test train consisted of twenty-five bogie coaches hauled by a CC 7100 locomotive. The coaches were fitted with LuR triple valves and electric control *for application only*. The brake equipment of the CC was supplemented by a control valve linked to the pressure in the pipe. The system thus effected was very simple (fig. 23). The λ of the whole train, under pneumatic control, was 0.97 and the weight hauled was 1 100 t.

Such a train, equipped for ordinary passenger service, could not be put into operation without the risk of serious consequences.

The tests consisted in making controlled stops and emergency stops from 120 and 140 km/h, with and without electric control.

The results amply confirmed expectations. While the most delicate braking operations were carried out in the course of the controlled stops without any adverse effects when electric controls were used, the use of the brake in the normal way gave rise to violent movements (15 balls reverse in the ball-accelerometer, experts will appreciate the significance of this) and even caused couplings to break. As for the emergency stops, they were carried out much more smoothly with electric control (maximum reaction 6/2 balls in place of of 15/15 with pneumatic control).

(It may be as well to explain what a ball-accelerometer is. It consists of a number of short inclined ramps with different gradients, on each of which there is a ball. The device is mounted on the level in the vehicle in which the measurements are being taken. The ramps are parallel to the longitudinal axis of the vehicle. Some ramps are directed towards the front, others towards the rear. Any acceleration, whether forwards or backwards, causes a number of balls corresponding to the acceleration to fall out. This apparatus, easily movable, is convenient in use, and gives accurate results which correspond closely with the physiological effect produced. These ball boxes are much used in brake trials in all the countries of Europe. Normally, they include 10 " forward " and 10 " reverse " balls. Sometimes, " strengthened " ball boxes are used, which include 15 " forward " and " reverse " balls.)

Moreover, a notable improvement in stopping distances has been achieved, as the figures in the table given below demonstrate.

It is to be noted that the increase in the train's λ is obtained purely through swift application of the brake, without any increase in maximum force exerted at the shoe, that is to say, *without reducing the safety margin available in relation to adhesion.* But it must be remembered, none the less, that the advantages obtained would have been substantially less if, instead of triple valves, modern high-speed-transmission distributors had been used. None the less there would have been some advantage.

The improvements obtained result from the considerable improvement in braking

| | Speed | Stopping distance | λ of train |
|---|---|---|---|
| Ordinary triple valve . . . . . . . . . . . . . . | 120 km/h<br>140 km/h | 845 m<br>1 180 m | 0.97 |
| Electro-pneumatic brake with normal application time (about 4 s) . . . . . . . . . . . . . . . | 120 km/h<br>140 km/h | 770 m<br>1 130 m | 1.08 |
| Electro-pneumatic brake with application time reduced to 2 s . . . . . . . . . . . . . . . . | 120 km/h<br>140 km/h | 730 m<br>1 000 m | 1.14 |

transmission time achieved with electric control. Measured between the first and the last vehicle (see page 113/14 above) it has been found, in fact, to be equal to 2 900 m/s, compared with 80 m/s with pneumatic control *in normal service*.

(In the case of an emergency application, the transmission speed would obviously have been higher, even with the triple valves. But service applications are the normal method of using the brake.)

Ease of handling is good since, on release, the brake's operation is eased by the use of a direct release brake.

## CONCLUSIONS

From this necessarily limited survey, the reader may perhaps obtain the impression that, despite the progress made recently in the design of distributors, there remain many problems relating to braking which still have to be resolved. In actual fact, the degree of perfection achieved is very high, but operating requirements have grown so greatly and so rapidly that difficulties in new respects are now being encountered. In any case, operating conditions have now approached the limits of the traditional brake's potentialities.

High speeds and, in particular, the operation of fast trains on lines normally signalled for speeds lower than those in operation, require increased braking performance. The risk is then incurred of subjecting the running surfaces of the wheels to harmful conditions. These conditions must be alleviated; this can be done by using disc brakes and also by the development, wherever possible, of rheostatic and regenerative braking. It may even happen that the retarding force permitted by adhesion is inadequate. Then the question of those brakes which do not depend on adhesion must be reconsidered. The electromagnetic brake is such a brake and its early faults appear now to be fully corrected. To follow another train of thought, brake operation on long passenger trains with high braking power is admittedly difficult. Modern distributors, which provide notable improvements in this respect through the high transmission speed which characterises them, still give rise to rather lengthy release times in the case of such trains. Ease of operation of the brake has hardly increased at all, at a time when talk of automatic operation and remote control of trains is beginning in connection with railway operation. These concepts can only be effectively employed in association with quick-acting brakes. Electric control of braking is an old idea in itself but it should now be developed. Its use will produce immediate practical advantages. All these matters are currently the subject of research and experiment on the S.N.C.F. The aim is that train braking, which is essential to both safety and comfort, should achieve the same rate of progress as has been evident for some years in railway affairs generally.

[ 656 .254 (43) ]

# Radio-operated centralized train control installation on the Malsfeld-Treysa line,

by Ernst SOCKEL.

(*Signal und Draht*, (*) No. 10, October 1955.)

**Summary**. — *The German Federal Railways have installed, on a main line of about* 40 *km (*25 *miles) length, a traffic control centre from which orders are radio-transmitted by the line controller to the trains. These orders are indicated to the drivers by means of cab signals. Receipt of each order is automatically acknowledged by radio from the train, and the position of the train is automatically reported to the controller, again by radio transmission, at certain points along the line, where the passage of the train causes the train number to light up on the operating panel.*

*The article describes :*

*— the surveys and experiments which preceded the installation of the radio-operated control centre;*

*— the installation itself and the method of operation, as well as,*

*— the additional telephone wire circuit installations forming part of the control centre.*

## 1. **Definitions.**

The German Federal Railways are endeavouring, as far as possible, to make use of the latest technical developments. Therefore, in view of the fact that the ultra-short wave installations in service in their own marshalling yards, and those used on the roads by the German Federal Post Office, have been found to work so well that they permit reliable intercommunication, at any time, between the vehicles and a fixed station, the German Federal Railways have now resorted to the use of wireless installations of this kind for the centralised traffic control on a section of line of some length, and have termed this installation "Betriebszugfunk" (i.e. "wireless communication with the train for operating purposes ", hereafter called " radio train control ").

### 1.1. *Radio train control with train position indication by telephone.*

In 1951, a radio train control installation was taken into operation, by way of experiment, on the branch line from Neustadt/Aisch-Steinach in the Nuremberg Region of the German Federal Railways where operating conditions are simple. With this installation, the position of the trains was reported by telephone, making use of ultra-short wave equipment designed for use in marshalling yards. The controller of this line was stationed at Windsheim Station, not far from the mid-way point of the line.

During the first trials, the controller gave the authorisation to proceed to the guard in charge of the train orally by means of the radio-telephone. This authorisation was equivalent to a " proceed " signal. The guard acknowledged the message and informed the controller of the position of the train, confirming at the same time that the train was intact.

Later on, the radio train control installations were supplemented by a selective call device in order to avoid confusion in the transmission of orders when several trains were using the line simultaneously.

In this case, the telephone call and the order to proceed were only received by the guard of that train whose number had been called by the controller. During that time, the installations of the other trains

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(*) Dr. Arthur Tetzlaff-Verlag, Frankfort-on-Main.

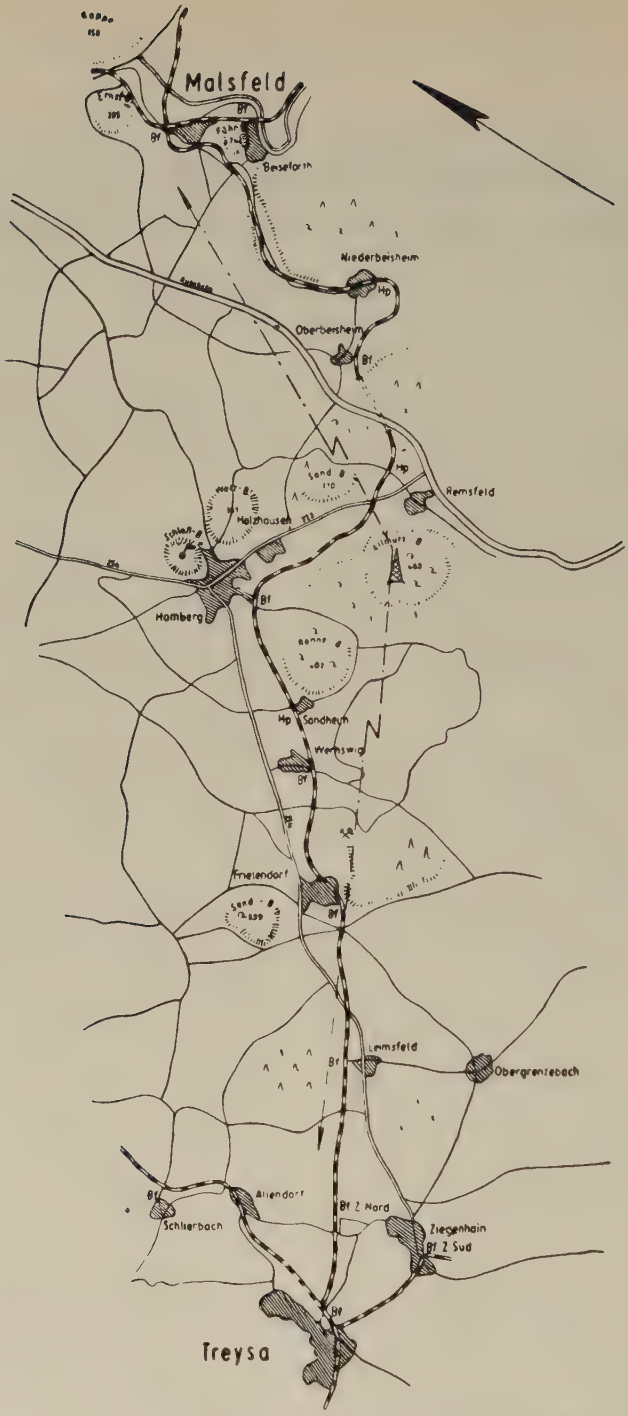


Fig. 1. — Map of the Malsfeld-Treysa line which is equipped with a radio train control system.

were blocked. In order to make the controller's duties easier, this installation was later supplemented by signal transmission apparatus which enable the controller, by operating the appropriate button, to transmit to the train certain radio signals which took the place of oral instructions over the radio-telephone, and which were indicated on a special signal panel mounted on the train. But it was still necessary for the train staff to acknowledge receipt of the signals to the controller orally by means of the radio-telephone. With a permanent installation, it would be necessary to insist on the automatic transmission also of the acknowledgment. The experiment has shown that, on branch lines where up to three trains may work on the line simultaneously, traffic can thus be reliably controlled from a single control centre.

### 1.2. *Radio train control with automatic report of the train position.*

On secondary lines where more than three trains may be working simultaneously, as well as on main lines with light traffic, it will be necessary to use radio train control in conjunction with automatic reports of the position of the trains. With this system, the selective transmission of signals and spoken words and the automatic acknowledgement of signals are supplemented by the automatic radio-transmitted report to the control centre of the position of the train at certain predetermined points along the line.

An installation of this type has been provided by the German Federal Railways on the line from Malsfeld to Treysa.

Apart from economic considerations, the choice of this line has been governed by the fact that the experiment was to be carried out on a single-track main line, and that it was desirable to gather experience on a line where radio transmission is difficult because of topographical conditions (undulating ground).

The 40.4 km (25.09 miles) long main line from Malsfeld to Treysa, which is part of the line from Eschwege to Treysa, passes through hilly and wooded ground (fig.1). Between Malsfeld and Niederbeisheim, the line runs through a deep cutting. Near Oberbeisheim in a tunnel of 900 m length. It is the nature of the ground which governed the choice of the site of the transmitter. The control centre is located at Homberg station. The transmitter has been erected on the top of Allmutsberg, a hill near Homberg. The distance between Allmutsberg and Treysa is about 20 km (12 miles) and that between Allmutsberg and Malsfeld about 13 km (8 miles) as the crow flies. At Homberg and Frielendorf are several important basalt and lignite plants. The daily traffic between Malsfeld and Treysa, during the period from 5 a.m. to 10 p.m. consists of thirty trains (not counting optional goods trains). During the morning, four trains are on the line at one and the same time.

The section Malsfeld-Treysa represents an alternative route for trains on the main north-to-south artery Hanover-Eichenberg-Frankfurt. But, since 1945, there have been no train diversions of any importance as regards the frequency of trains or the length of the period of diversion.

In order to reduce, as much as possible, the cost of equipping locomotives and railcars with radio installations, it has been decided not to apply the radio control method to diverted trains. These trains use the line on written orders.

#### 1.2.1. *Field-intensity measurements.*

In order to determine the most favourable position of the transmitter, the polarisation and beam concentration of the necessary transmitting power, and the received field intensities along the line, the whole of the Malsfeld-Treysa line was made the subject of a preliminary radio-technical survey. Prior to the survey proper, topographical sections were prepared for the three highest hills in the vicinity of Homberg station where a transmitter might be installed, viz. Allmutsberg (463 m), Schlossberg (378 m) and Ronneberg (402 m). As far as Ronneberg is concerned, calculations based on the topographical sections showed good reception conditions in the direction of Treysa, whilst the calculated receiving voltages on the section Oberbeisheim-Malsfeld were lower than those from the other two hills. The Ronneberg alternative was therefore eliminated from the further survey.

The measurements on Allmutsberg and Schlossberg were carried out with equipment of 2 m wave length, designed for road vehicles. This equipment was installed in a " Volkswagen " bus. The antenna systems were mounted on a telescopic mast of 30 m height (fig. 2), so that the aerial could be rapidly erected and could be turned, when erected, in any direction.

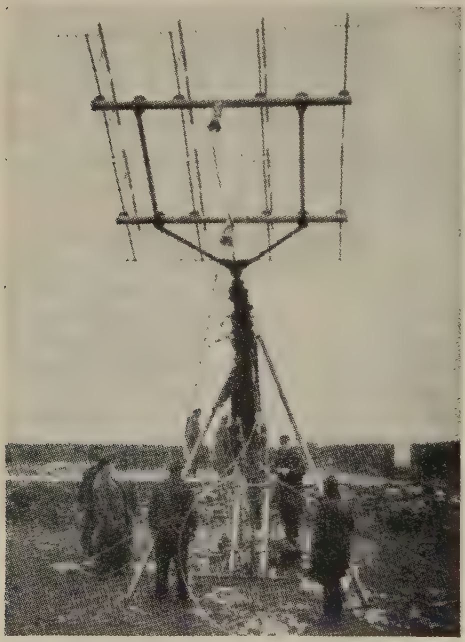


Fig. 2. — Telescopic mast with system of aerials.

The mobile radio equipment for 2 m wave length was installed in the radio testing car of the German Federal Railways. Both the stationary and mobile equipment were connected to measuring instruments, which recorded the receiving voltages (limiter current) and the low-frequency output voltages. To facilitate interpretation the two-system recorders in the radio test car were arranged to record with a time lag corresponding to the distance.

The evaluation of the strip charts obtained during the first trips when a transmission power of 20 W was used had shown that it would be desirable to increase the field intensity five times. It was therefore decided to work with two antenna systems of eight dipoles of television type (antenna gain $G = 2 . 16 = 32$) in one direction. (The increase in field intensity with one set of two antenna systems amounts to $\sqrt{32} = 5.7$). As it will later be necessary to beam simultaneously in two directions (Treysa and Malsfeld), it is necessary to use twice the transmission power. It was therefore decided to use a transmission power of 50 W.

Tests with horizontal and vertical polarisation of the emitters showed the superiority of vertical polarisation.

The survey results from Allmutsberg were better than those from Schlossberg. Whilst, in the case of the Schlossberg transmitter, the receiving voltages were equal to, or less than, 5 $\mu$ V on sections totalling 6 % of the whole line, this figure was reduced to 1 % in the case of Almlutsberg, under equal transmitting and receiving conditions. In the course of a trip over the line, the receiving voltages varied between 3 $\mu$ V and 1 000 $\mu$ V. It is only during the short periods when the high-frequency voltage drops below 5 $\mu$ V that the low-frequency voltage is also fluctuating, but this is of no significance to the transmission of signals and spoken words. Inside the Oberbeisheim tunnel, radio-communication between station and train is not possible.

The necessary height of the Allmutsberg aerial was found to be 40 m (131' 2 3/4"). The final antenna arrangement is shown in figure 3. In each direction, two systems of eight television-type dipoles with vertical polarisation are mounted one above the other, two systems for the signal channel and two for the voice channel, i.e. eight television-type systems of eight dipoles all told, for both directions together. The

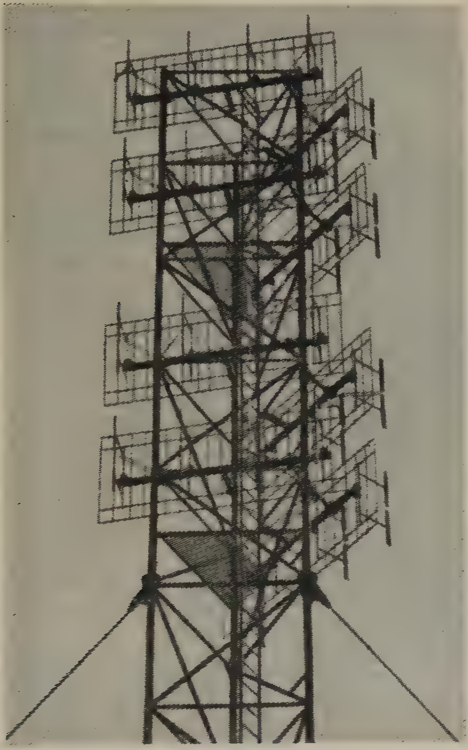


Fig. 3. — Arrangement of aerials at the Allmutsberg transmitter.

angle between the two directions (Treysa and Malsfeld) was found to be 140°. The half-intensity angle of the aerials is about ± 15°, both in the horizontal plane and in the vertical plane. The aerial mounted on the railcar is shown in figure 4.

1.2.2. *Test runs.*

For nearly three months, preliminary tests were carried out on the section Homberg-Wernswig. For this purpose two mobile wireless sets for signal and voice transmission on 2 m wave length were installed on the top of Schlossberg, near Homberg, with two Siemens wave trap aerials mounted on a telescopic mast of 15 m height. It was possible to forego concentration by means of eight-dipole systems as the preliminary tests were confined to a short section of 4.6 km. These prolonged tests had the purpose of testing the reliability and safety of the transmission of signals and messages. At Homberg station, an operating desk was installed, with a control section consisting of order transmitters, and message receivers. The desk was equipped with keys and switches for the transmission of orders (signal transmission) and for the establishment of a telephone connection, and with signal lamps indicating the incoming messages and the occupancy of the signal and voice channels (fig. 5).

The operation of this method of signal transmission will be explained later as part of the description of the permanent installation.

Between the control centre at Homberg station and the Schlossberg transmitter, the audio-frequencies were transmitted by means of two cable pairs. There was no electrical or mechanical exclusion of mutually conflicting operations. Proper operation was safeguarded by means of instructions.

The mobile installations, consisting of an operating set, the order receiver and message transmitter with relay sets and position-indicating magnets, a box locking a key for the operation of points, a signal lamp panel, outside indicator lamps, trans-

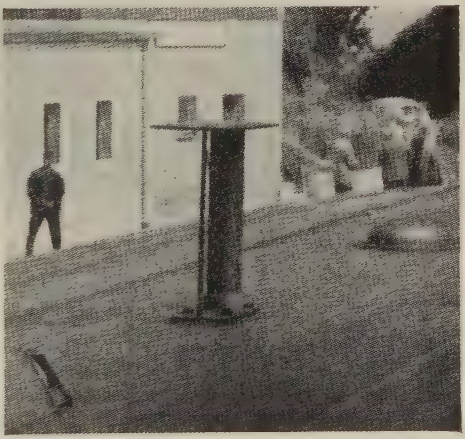


Fig. 4. — Aerial on the roof of a railcar.

mitter and receiver including aerial were mounted in a " MCi " vehicle (fig. 6).

All operations during 1 090 test runs were entered in special forms, and any irregularities were specially recorded. The evaluation of these forms yielded important data for the final design of the equipment from an operating and signalling point of view. The test also showed that the radio transmission was working reliably. The signal aspects received were always identical with the orders transmitted, and any failures were always such as to err on the side of safety. For instance, when a signal was not received by the mobile installation, the signal displayed on the vehicle at the appropriate points of the line always indicated the " danger " position or, if the position indicator was out of order, the " trouble " position.

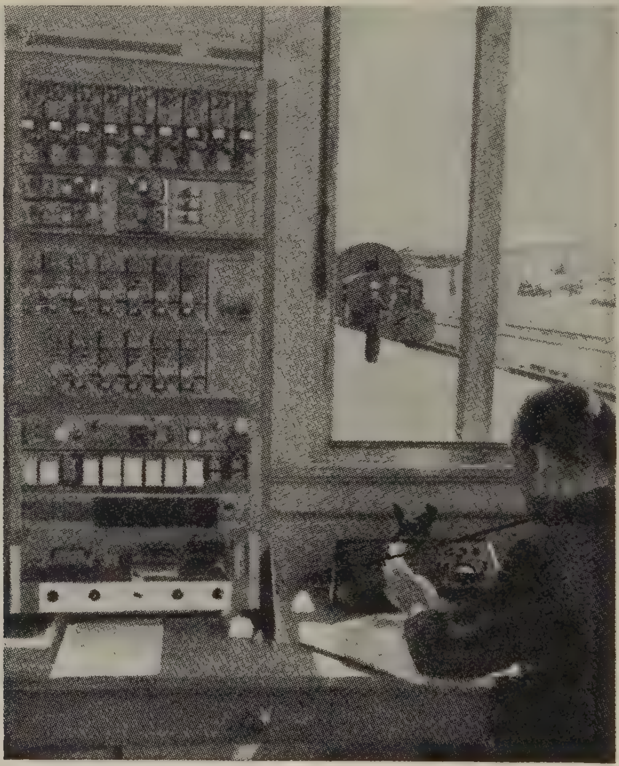


Fig. 5. — Control centre for experimental working.

## 2. **Description of the installations.**

### 2.1. *Radio transmitter Homberg (Allmutsberg).*

The permanent transmitting and receiving installations are housed in the radio building on the top of Allmutsberg (fig. 7). There are four sets, viz. two transmitters and two receivers for the transmission of signals, and two transmitters and two receivers for voice transmission (fig. 8). The second transmitters and receivers are stand-by units which are automatically connected if

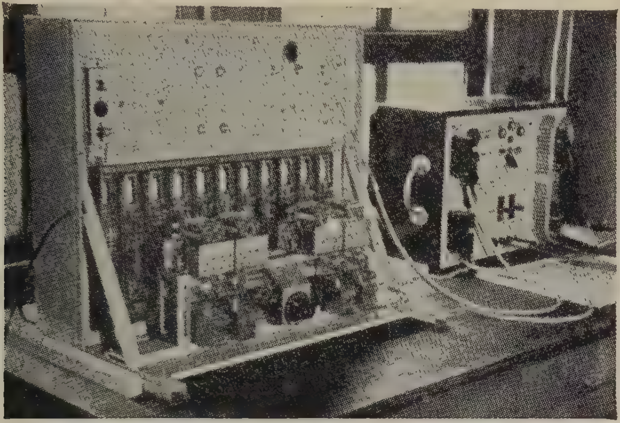


Fig. 6. — „ MCi " vehicle-mounted equipment for experimental working.

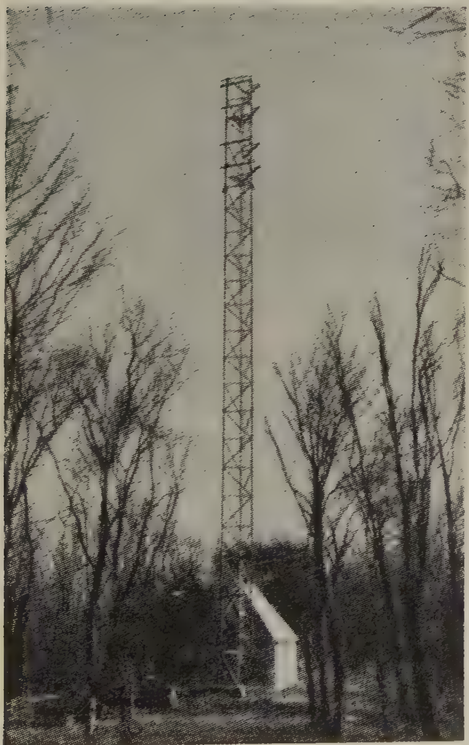


Fig. 7. — Allmutsberg radio transmitter.

the operating units should fail. The building is connected with the Homberg control centre by means of a twelve-pair telephone cable of 4.5. km length. Current for the installations is taken direct from the grid by means of a power cable from Homberg station. If the power should fail, a continuous 3-phase current converter unit is automatically switched in at Homberg control centre. If the breakdown is of long duration, the controller is able to start, from the operating panel, a stand-by set which will then take over the current supply.

The transmitter station of Allmutsberg is not manned. The installations are therefore safeguarded by a burglar alarm and a smoke alarm.

The audio-band radio transmitter works with a frequency of 171.0 MHz. and the audio-band receiver with a frequency of 166.5 MHz. Compared with these frequencies, those of the signal channel are staggered by .1 MHz, being 171.1 MHz for the transmitter and 166.6 MHz for the receiver. Transmitter and receiver of one channel are connected to the same aerial. An antenna switch separates the transmitter and receiver frequencies (duplex operation). The sending power of the stationary installation is 50 W, that of the vehicle-mounted installations 20 W.

2.2. *Installations on the vehicles.*

Four steam locomotives (for freight traffic) and seven rail buses (for passenger traffic) have been equipped with radio train control installations. In normal operation, two steam locomotives and four rail buses are in service.

1 hooter or buzzer, providing an acoustic indication of the change of a signal indication;

2 outside lamps, and

1 accumulator battery of 24 V which, in the case of the rail buses, is charged by an axle generator and, in the case of the steam locomotives, by a turbo-generator.

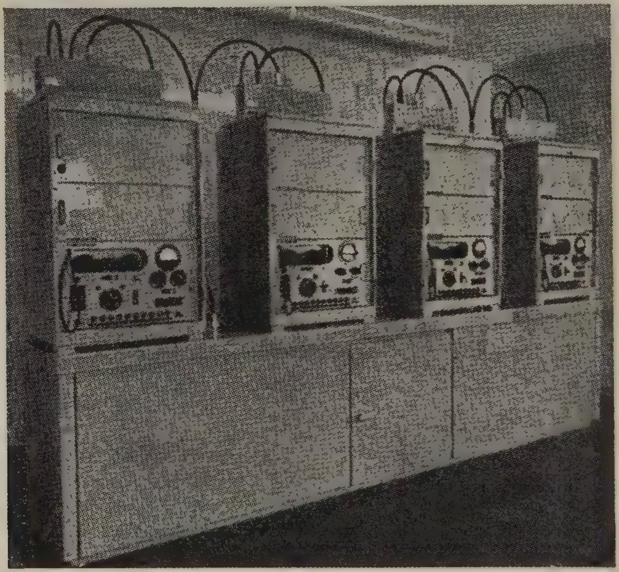


Fig. 8. — Radio equipment at Allmutsberg transmitting station.

The equipment of the vehicles includes the following items :

1 relays cabinet with radio transmitter and receiver, audio-frequency section, relays section and current supply (fig. 9);

1 aerial mounted on the roof of the vehicle;

1 operating set with telephone receiver and operating keys (fig. 10);

2 position indication receivers to ascertain the position of the vehicle at certain predetermined points along the line (fig. 11) (section entry point, point of brake application, section end point);

1 key locking box;

1 panel of signal indicator lamps (fig. 12);

In the rail buses, lamp indicator panel and operating set are provided in both driving cabs. The operating sets are switched in according to the direction of running (fig. 13). On the vehicles, radio transmitter and receiver are used jointly for signal and voice transmission. They are normally connected to the signal channel frequencies but are switched over to audio-frequencies when the telephone receiver in the vehicle is lifted.

2.3 *Audio-frequency installations.*

The orders of the control centre are transmitted to the vehicles, and the messages from the vehicle to the centre, as audio-

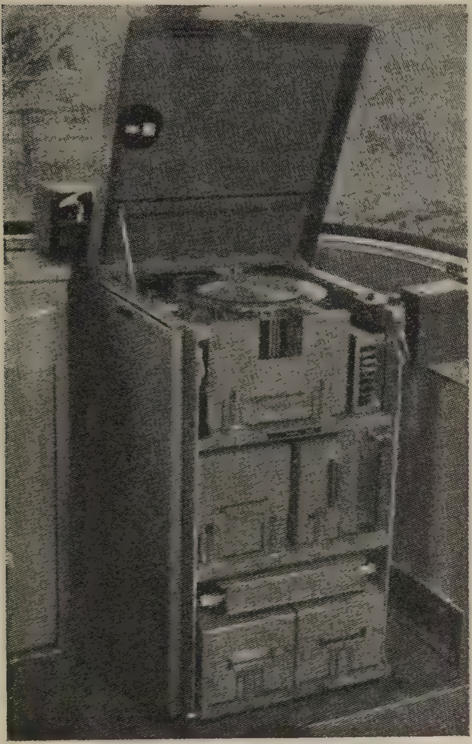


Fig. 9. — Radio transmitting and receiving equipment mounted on the railcar.

frequency pilot signals via the radio channel. With a few exceptions, every order and every message is formed by two audio-frequencies. In addition to the orders and messages, the transmission includes a train code signal, consisting of two further audio-frequencies. The orders and messages thus consist of a combination of four audio-frequencies.

With the two audio-frequencies for the train code signal, the signal order will only be transmitted to that vehicle for which it is destined. In the case of a message from the vehicle to the control centre, the message is decoded at the centre with the aid of the train code signal transmitted along with the message. For instance, the automatic message transmitted by a train passing a section entry point, together with the appropriate train code signal, is dealt with by the relay apparatus of the control centre in such a way that the train number of this train is switched forward to the correct section of the operating panel.

The frequencies for the formation of orders, messages and train code signals are in the frequency range between 300 Hz and 3 000 Hz. As far as the orders are concerned, these are produced in an order transmitter at the control centre by means of valve generators. Each generator is

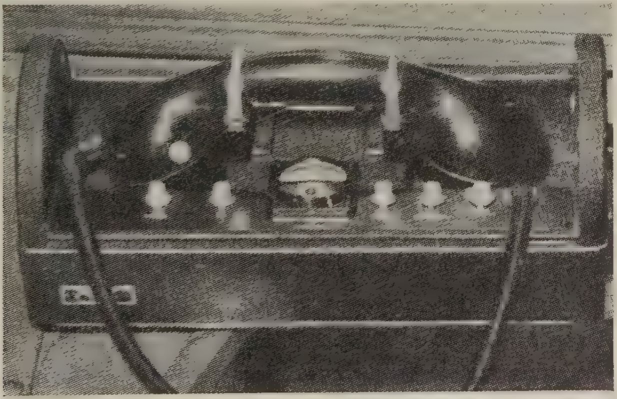


Fig. 10. — Operating set mounted on the railcar.

activated by a variation of the grid potential, by means of a relay. The audio-frequencies for the messages are received at the centre by a message receiver which consists of thirteen individual receivers (three for the audio-band and ten for the signal band). Each of these individual receivers consists of a resonant circuit tuned to the audio-frequency concerned, and of a valve section. The anode circuit of the valve section contains a relay which is operated through the resonance excitation of the resonant circuit. The vehicles are equipped with order receivers and message transmitters. The order receivers have eleven selection circuits and seven valve sections, whilst the message transmitters have eleven message generators. The design of the order receivers is similar to that of the message receivers at the control centre, whilst the message transmitters correspond to the order transmitters.

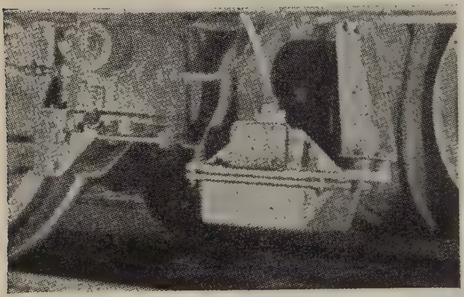


Fig. 11. — Position indication receiver on the railcar.

2.4. *Homberg control centre and line-side stations.*

*a*) The line controller in charge of Homberg control centre controls the traffic of the entire line with the collaboration of the line-side stations which are manned by a local official (ÖB) who receives his orders from the controller. Junctions of sidings along the line are regarded as “ unmanned line-side stations ”, there being no local operating official. The stations at the ends of the line are manned by local control officials who are, as before, responsible for the control of these stations independently of the line controller.

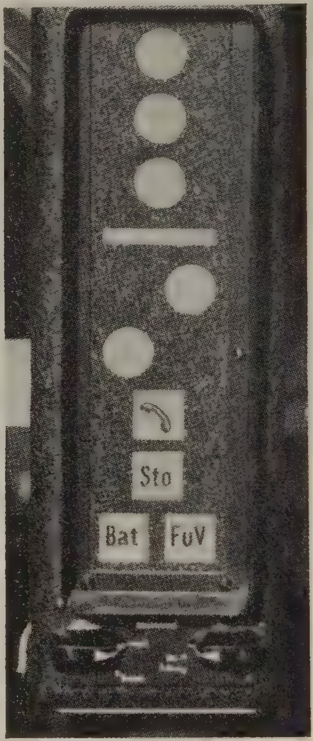


Fig. 12. — Lamp panel for signal indications.

*b*) The semaphore signals (main and distant) on the line have been removed. Where flank protection is not afforded by means of protective points or track locks, special ground signals (Gleissperrsignale) have been provided. The former home signals and distant home signals have been replaced by trapezoidal signboards and cross-shaped signboards, The semaphore “ home ” and ,, distant home ” signals at the stations at the ends of the line have remained. At each of the points where the trapezoidal and cross-shaped signboards are erected, there are mounted by the side of the track, two permanent magnets with different polarisation which serve to indicate the position of the train or to mark the point of brake application. The magnets installed at the trapezoidal signboards report the position either as ,, section entry point " or as ,, section end point " according to the direction of running (fig. 14 and 15).

(*c*) The control centre is linked with the manned line-side stations by means of an insulated overhead two-wire line to which the remote control devices of the control centre and of the line-side stations are connected in parallel. This single-two-wire line serves for the transmission of all the orders from the control centre to the line-side stations, and of all the messages from the line-side stations to the control centre. One transmission takes about 1.2 s. Through this remote control system, the individual line-side stations are made dependent on the control centre.

(*d*) The operating panel at the control centre is similar in design to the operating panel of an entrance-exit all-relay type signal cabin (fig. 16 and 17). The momentary position of the individual trains is indicated by the lighting up of the train numbers in the open-line and station sections of the track diagram. Because of the peculiarities of the radio control centre, the train number indicating apparatus has been amplified to serve as a link between the signal circuiting proper and the radio-transmission installation. The signal circuiting proper has a function similar to that of an all-relay type signalling installation. The functions of the section block system are exercized by the relay units of the control centre in such a way that the position indication received when the vehicle passes a section entry point may be said to correspond to the approach locking, whilst the remote-controlled message of the line-side station to the effect that the approach route is released (also implying that the train has entered intact) corresponds to the " line clear " message.

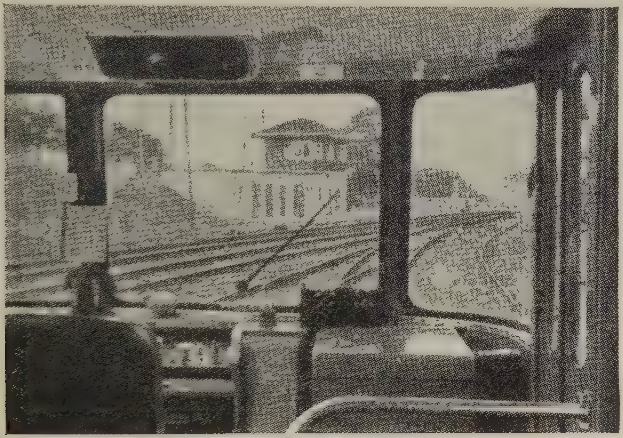


Fig. 13. — Driving cab of a railcar, with radio and relay installations, operating set, signal lamp panel and key locking box.

### 3. **Method of operation.**

3.1 *Radio transmission of signals.*

An order from the control centre to the power vehicle is transmitted in the following way :

When all the prerequisites for the sending of a signal order to the train have been fulfilled (details will be described later as part of description of a train run), four generators of the order transmitter at the control centre are operated. The audio-frequency combination produced by these four generators reaches the Allmutsberg transmitter through one pair of conductors of the telephone cable. The fundamental frequency produced by the pilot oscillator is frequency-modulated by the audio-frequency combination, amplified in stages until reaching the required value of 171.1 MHz, and finally transmitted by the antenna. In the power vehicle, the high-frequency signal is received at the high-frequency stage of the receiver. After two intermediate frequency changes and amplification, the audio-frequency combination is regained and introduced into the order receiver, causing by means of a relay set the appearance, on the signal panel, of the signal corresponding to the audio-frequency combination concerned. The signal is only shown on that vehicle whose pre-set train code number corresponds to the train code signal transmitted along with the frequency combination. With all other power vehicles, the high-frequency signal, though received by them, does not release any signal indication. The order received is automatically acknowledged from the vehicles by the radio-transmission of the same audio-frequency combination to the control centre where the receipt of the acknowledgment has the effect of interrupting the order transmission. A message from the power vehicle to the control centre, e.g. a position report, is similarly radio-transmitted as a frequency combination.

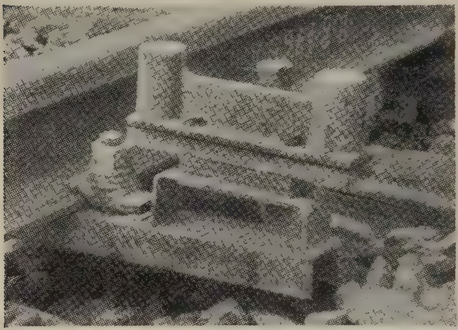


Fig. 14. — Position indicator magnet.

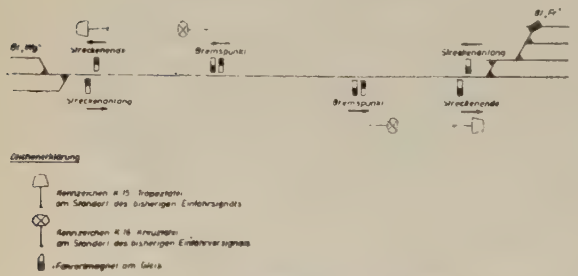

Bf. Wg
Streckenende
Streckenanfang
Bremspunkt
Bremspunkt
Streckenanfang
Streckenende
Bf. Fr
Zeichenerklärung
Kennzeichen K 15 Trapeztafel
am Standort des bisherigen Einfahrsignals
Kennzeichen K 16 Kreuztafel
am Standort des bisherigen Einfahrvorsignals
Fahrortmagnet am Gleis

Fig. 15. — Arrangement of position indicating magnets.

*N. B.* — Streckenanfang = section entry point. — Streckenende = section end point. — Bremspunkt = point of brake application. — Zeichenerklärung = legend. — Kennzichen K 15... = trapezoidal signboard K 15 at the site of the former home signal of the station. — Kennzeichen K 16... = cross-shaped signboard K 16 at the site of the former distant home signal of the station.—Fahrortmagnet am Gleis = position indicating magnet by the side of the track.

### 3.2. *Sequence of events during a train trip.*

Let us assume that a train has been formed at Frielendorf station which is now intended to proceed to Wernswig station.

(*a*) The driver of the locomotive informs the line controller via the radio-telephone that the train is ready to leave, stating the name of the station, the number of the station track, and his code number; he then puts the receiver down.

The line controller now selects, through operating the train number keys, the code number and train number at the train number control panel on the operating panel. Having ascertained that the code number and train number shown on the control panel are correct and complete, he simultaneously operates the control panel key and the key of the corresponding track, thus transferring the two numbers into the appropriate section of the track diagram. The two numbers in the control panel are extinguished, and only the train number is shown on the track diagram. At the same time, the track section on the diagram shows up in red (fig. 18*a*). The line controller now calls the engine driver via the radio-telephone, using the latter's code number in order to verify the correct report of the code number by the driver and the correct storage of this number by himself.

(*b*) When the conditions pre-requisite to the departure of the train are fulfilled, the line controller operates, on the operating panel, the corresponding start signal push-button of Frielendorf station and at the same time, that of the home signal of Wernswig station, both for the duration of about one second. This causes the locking of the desired route by means of relays at the control centre, a fact that is indicated on the operating panel by a flashing yellow light along the route thus locked, and by the lighting up of arrows indicating the direction of running (fig. 18*b*). At the same time, the order to set up the route is sent out to Frielendorf station through the remote-control system. At Frielendorf station, the corresponding order to set up the route is lighting up on a signal panel (fig. 19). The route is set up in the normal way, and locked through the operation of the route lever. The local official then makes sure that the track is physically clear, and back-locks the route by the operation of a route blocking device. Keyboard locks of the permanent current type, mounted above the

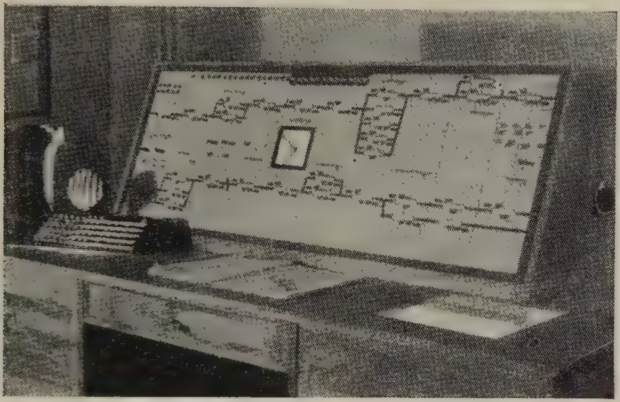


Fig. 16. — Operating panel and telephone set with switchboard at the radio control centre.

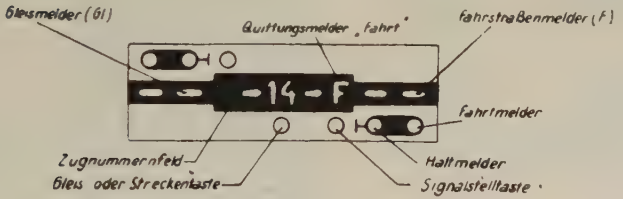
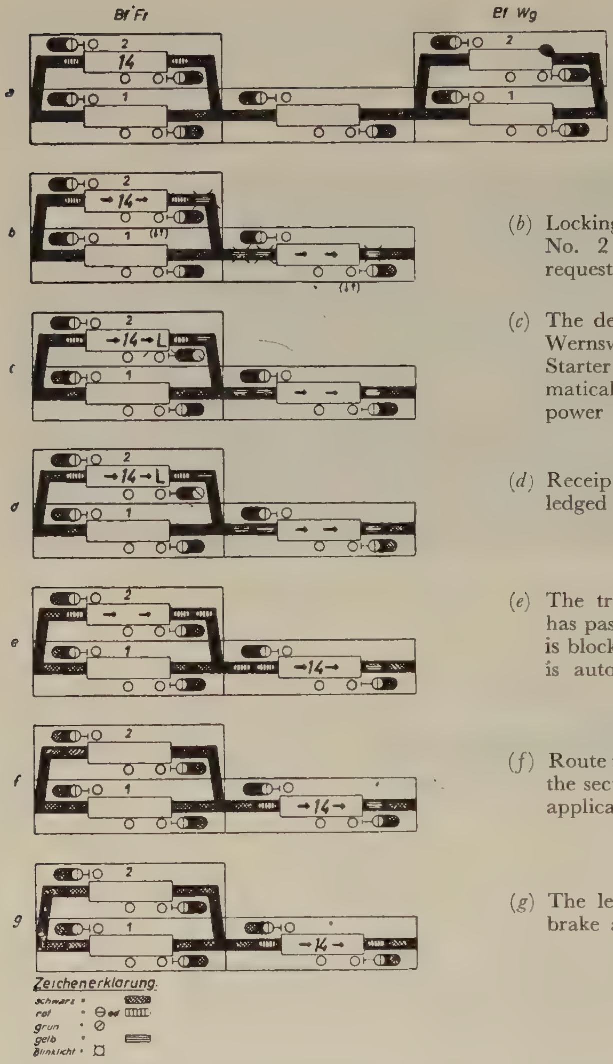


Fig. 17. — Part of track diagram type operating panel representing an open-line section.

*N. B.* — Gleismelder = track occupancy indication. — Quittungsmelder " Fahrt " = indication that the order to proceed has been received on the train. — Fahrstrassenmelder = route indication. — Zugnummernfeld = panel indicating the train number. — Gleis- oder Streckentaste = station track or open-line track key. — Fahrtmelder = pilot light indicating the " proceed " position of a signal. — Haltmelder = pilot light indicating the " danger " position of a signal. — Signalstelltaste = signal operating key.



(*a*) Train 14 is standing in Frielendorf station, No. 2 road. Departure prohibited.

(*b*) Locking of the route for departure from No. 2 road towards Wernswig has been requested.

(*c*) The departure route for No. 2 road towards Wernswig has been locked as requested. Starter signal (HP 2) has been stored automatically and has been transmitted to the power vehicle.

(*d*) Receipt of the starter signal has been acknowledged by the vehicle.

(*e*) The train has departed, the leading vehicle has passed the section entry point. Departure is blocked, and route release at Frielendorf is automatically requested.

(*f*) Route released. The train is in section between the section entry point and the point of brake application.

(*g*) The leading vehicle has passed the point of brake application. Entrance is still blocked.

Fig. 18. — Sequence of indications of a train departure on the operating panel.

*N. B.* — Zeichenerklârung = key to symbols. — Schwarz = black. — Rot = red. — Grün = green. — Gelb = yellow. Blinklicht = flashlight.

route locking apparatus, ensure that the locking is confined to that route which the line controller has ordered to be locked. The locking of the route is automatically reported to the control centre via the remote-control system.

This report, in its turn, causes the operation at the control centre of a number of relays which serve to safeguard the route and which have additional verification and control functions. The route is now marked on the track diagram by a permanent yellow light, and the star signal pilot light shows green. At the same time, the order to proceed is radio-transmitted to the vehicle (a fact which is indicated by the flashing of the acknowledgment indicator) (fig. 18*c*), and is immediately acknowledged by automatic radio-transmission. The receipt of the acknowledgment at the control centre causes the order transmission to cease. On the operating panel, the flash-light of the acknowledgment indicator changes into continuous light (fig. 18*d*).

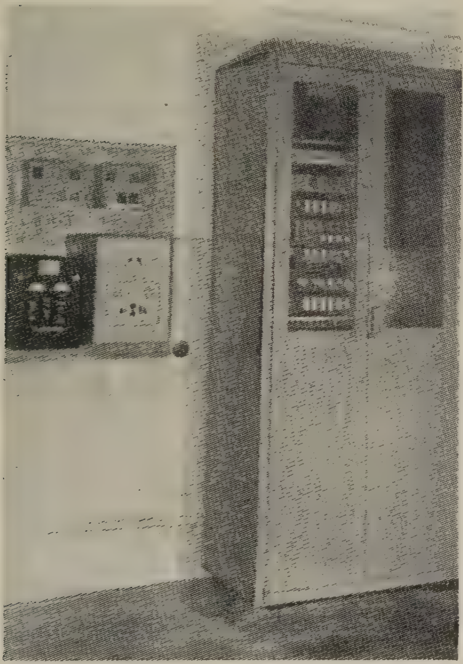


Fig. 19. — Relays cabinet, signal panels and rectifier at a line-side station.

On the locomotive, the order to proceed thus received causes the red light on the signal panel to be extinguished and the green/yellow (or green) light to show. At the same time, the sounding of a hooter draws the driver's attention to the change in the signal. The hooter can be cut out through the driver pressing a button. In order to inform the guard in charge of the train that the cab signal is in the " proceed " position, lamps are fitted to the outside of the vehicle on either side which show white when the signal is clear.

(*c*) The train departs as soon as the guard has given the signal. As soon as the leading vehicle passes the section entry point, the green cab signal is automatically extinguished, and two yellow lights arranged diagonally from bottom left to top right show up as an advance indication

The hooter sounds again.

At the same time, an automatic message is now radio-transmitted from the vehicle to the control centre, indicating the passing of the section entry point. This message is automatically acknowledged by the control centre. On receipt of the acknowledgment, the transmission of the message from the vehicle is stopped.

At the control centre, the message to the effect that the locomotive has passed the section entry point causes several automatic reactions. The pilot light of the start signal again shows red. Route indicator and the first track circuit of the corresponding section on the track diagram show red. The train number is extinguished in the track diagram of the station but is now shown on the open-line section (fig. 18*e*). Via the remote-control system, the train is announced to Wernswig station where a corresponding signal light on the signal panel now shows red.

At the same time, the remote-control system is used to transmit to Frielendorf station the order to release the route. This order is indicated by the lighting up of the corresponding signal light on the signal panel. The local official is now able to release the route locally, by operating the route release key. The release of the route is again reported to the control centre via the remote-control system with the result that the relay locking of the route at the centre is again released. On the operating panel, the red lights of the track sections and of the route indicator are extinguished (fig. 18*f*).

When the leading vehicle passes the point of brake application, the advance indication changes into the corresponding main indication. At the same time, the passing of the point of brake application is automatically radio-transmitted to the control centre and automatically acknowledged by the latter. On the operating panel, the second track circuit of the section shows red (fig. 18*g*).

(*d*) At Wernswig station, the route for the entering train is set up in a similar way. When the locking of the route by Wernswig station has been reported, the relays at the control centre again work in the manner already described. Again, the order to proceed is radio-transmitted to the locomotive. In this case, however, as the train is still occupying the section between section entry point and the point of brake application, the cab signal appears as an advance indication on the signal panel, e.g. in the form of two green lights arranged diagonally from bottom left to top right. Had the train, at the time of the order transmission, already been located between the point of brake application and the section end point (in which case the cab signal would, on passing the point of brake application, have changed automatically without intervention of the control centre from advance indication " yellow/yellow " to main signal indication " red "), there would be an immediate cab signal indication for the home signal, e.g. green, and an advance indication for the starter signal (which has not yet been cleared), viz. yellow/yellow.

The relay set on the vehicle contains a device which controls the sequence of the different section points passed. All further actions on the part of the line controller and the local official, and all further operations at Wernswig station, at the control centre and on the vehicle are similar to those described for the departure from Frielendorf station.

### 3.3. *Operation in case of a breakdown in the signal transmission.*

If the passage of a train at a pair of position magnets causes the trouble indicator in the signal lamp panel to light up, there is trouble either at a position magnet, at the position indication receiver, at the signal installation, or in the signal transmission. If the trouble indication is received when the train passes a section entry point or a point of brake application, the train is allowed to proceed to the next section end point. But a written order is required for the train to proceed beyond that point.

If the trouble indication is received when the train passes a section end point, the train may proceed to the nearest stopping place in the station.

Subsequently, the instructions of the line-controller must be followed.

If there is a breakdown in the radio-signal as well as the radio-telephone communications, the trains must proceed on written instruction which the guard in charge of the train receives at the signal telephone or at the station telephone.

### 3.4. *Testing of radio installations.*

In order to detect trouble as quickly as possible even at times of light traffic, the fixed radio installations are automatically tested at intervals of ten minutes. The testing device can also, at any time, be switched in manually by the line controller from the operating panel. The radio installations are tested as follows.

The transmitters are modulated by means of an audio-frequency of the order transmitter. The audio-frequencies are changed for each test so that order transmitter and message receiver can be tested at the same time.

The difference between the frequencies of the transmitter and receiver of the same radio channel (signal or voice channel) is always 4.5 MHz (e.g. 171.0 MHz and 166.5 MHz). The high-frequency transmission currents are therefore changed into the receiver frequencies by means of an auxiliary oscillator which is fitted between the aerials on their support. The test of the transmission channel is checked by a measuring instrument which automatically switches over from the operating units to stand-by units if the transmission is found to be faulty. The switchover is indicated to the line controller on the operating panel.

## 4. Telephone installations.

### 4.1. *All-lines telephone station.*

With the exception of the regional signal telephone installations, the telephone lines terminate at an all-lines telephone station at the control centre at Homberg station.

In addition to the general railway telephone connections (Basa system) and the local lines connecting with other points at Homberg station, the call centre has direct lines to the officials in charge of operations at Malsfeld and Treysa stations, and to the line-side stations. Telephone communications with these external points are established over a joint two-wire line which is operated like the telephone circuit of a train control system as an auxiliary circuit of the " Basa " automatic system, with table microphones. The same equipment is used for the radio-telephone com munications with the locomotives and rail cars on the line.

### 4.2. *Signal telephone installations.*

For the telephone transmission of signal orders in the case of a breakdown of the signal radio-transmission system, signal telephone cabins are installed at each section end point in the vicinity of the trapezoidal signboards. As it is undesirable, on a line not equipped with telephone cable, to provide individual lines between each signal telephone and the control centre, the signal telephones are parallel-connected over one two-wire line on each of the sections Niederbeisheim-Homberg and Homberg-Ziegenhain Nord. In order to avoid confusion in the telephone transmission of signal orders, these regional signal telephone lines are equipped with special selective call devices.

At the control office, the regional signal telephone lines are connected to a signal order telephone set. To each signal telephone set on the line corresponds a key on the telephone set at the control centre. When the key is operated, a connection is established between the line controller and the signal telephone set concerned, whilst all other signal telephone sets are blocked. Similarly, all other signal telephone sets on the same circuit are blocked when a call is made from one set to the line controller. By putting through a counter-call, the line controller is able to make sure that he is connected with the signal telephone set from which the call is initiated. In the case of a breakdown in the relay equipment of the installations, emergency operation by means of local batteries is possible in both these installations.

## 5. Maintenance.

The maintenance of the radio transmission system is entrusted to two signal inspectors and a telecommunications inspector. One of the two signal inspectors is responsible for the maintenance of the signalling installations at the control centre, including current supply, relay sets for the transmission of signals to the vehicles, and relay sets for the remote-control system at the line-side stations. The other signal inspector is responsible for the maintenance of the fixed outdoor installations. The maintenance of the radio equipment of the fixed installation, and of the vehicle-mounted installations with the audio-frequency equipment and the automatic radio testing devices is the responsibility of the telecommunications inspector. In the case of failures involving the replacement of radio equipment on the vehicles, the Basa telecommunications maintenance engineers at Malsfeld and Treysa are called upon to give assistance.

## 6. Reflections on the economic aspects of the radio train control system.

Since all operations are controlled from a single control centre at Homberg, the duties normally incumbent upon the local operating officials at the line-side stations are eliminated. The work at these stations, such as the setting of points, locking and release of routes, forwarding of " train intact " reports, etc. is carried out by signalmen. The elimination of the operating control duties at the line-side stations has not always resulted in *direct* savings in the *number* of staff at the smaller stations. But it is possible to assign additional duties to the operating staff and thus to effect savings elsewhere. It is therefore intended to eliminate the manning of level crossings and to replace the locally operated gates by flashlight installations or by gates with telecommunications equipment which are, on request by road users, opened by the station staff by means of remote control. Other savings are to be made by closing the booking offices and issuing tickets on the trains. When all these measures have been taken, the number of staff required for this line will have been reduced by half.

The installation costs are expected to be balanced by savings within five or six years.

[ **624** .8 (44) ]

# The reconstruction of the swing span of the Caronte viaduct,

by L. Carpentier,

ngénieur principal de la Division centrale des ouvrages d'art de la S.N.C.F

(*Acier - Stahl - Steel,* December 1955.

The viaduct across the Caronte lagoon, a short distance away from the Berre lagoon, constructed between 1909 and 1914 under the direction of M. Sejourné for the railway line from Miramas to l'Estaque (fig. 1), is a steel bridge for two tracks, 943 m (3 094 ft.) in length, and weighing altogether 10 000 t.

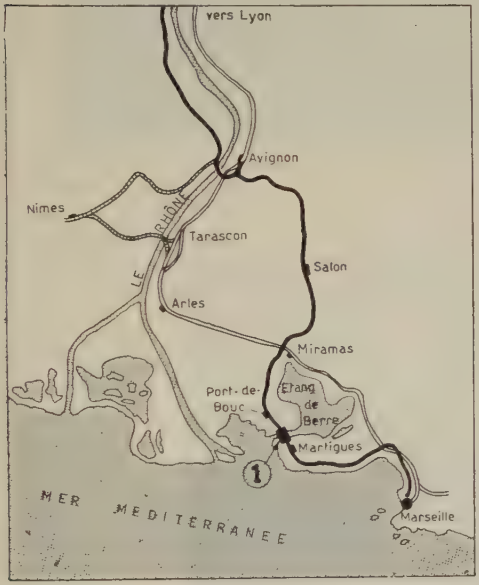


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Fig. 1. — Area map showing the position of the Caronte viaduct.
1. Viaduct.

It consists of two fixed spans of 51.20 m (168 ft.) length on the Port-de-Bouc side, a swing section of about 114 m (374 ft.) length with two identical wings of 56.50 m (185′ 4″) length which crosses the ship canal connecting the Berre lagoon with the Mediterranean at a height of 23 m (75′ 6″) above water level, and eight fixed spans of 82.50 m (270′ 2″) length on the Martigues side.

Next to the Cubzac viaduct, this is the longest steel bridge in France, and one of the most remarkable ones as far as design and position are concerned (fig. 2).

In August 1944, during the Allied advance in the Provence, the Germans cut the fixed span of 51.20 m (168 ft.) adjacent to the swing bridge, and destroyed the swing bridge itself by blowing up the central tower consisting of masonry (fig. 3).

As soon as the volume of traffic between Lyons and Marseilles called for the restoration of the Miramas-l'Estaque line, the fixed span was lifted and repaired and a temporary bridge was built at the site of the swing span which had previously been cut off in order to clear the fairway for maritime traffic.

The arrangements for the temporary bridge were, from the outset, designed with a view to the eventual construction of the permanent bridge.

## Choice of the type of permanent bridge.

The original swing span had been chosen by M. Sejourné on the basis of an enquiry on movable bridges made in America in 1905.

Spans of the drawbridge type, such as Scherzer or Strauss bridges, which were hardly known in France at the time when the Caronte bridge was first constructed, did not appear suitable for a railway bridge of such large span.

The design and construction of their supports and of their roller tracks on the adjacent spans, as well as the wind resistance of the bridge in this Mistral-swept region would have given rise to serious problems. Moreover, it would have been difficult to reconcile the outward appearance of the bridge with the site of the Caronte bridge which had not yet been affected by the present harbour installations.

Lifting spans were likewise ruled out at the time as it was difficult to predict the maximum height of the masts of ships which would pass through the canal.

It was therefore decided to adopt the solution of a swing span, and its construction has shown that it is possible to construct a steel bridge without disfiguring the landscape.

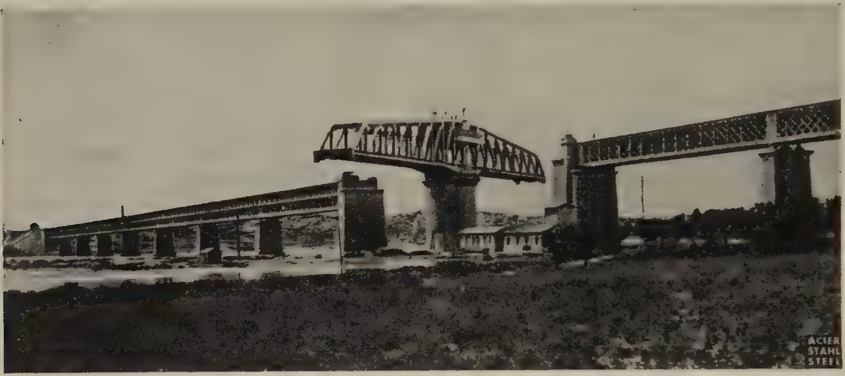

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Fig. 2. — General view of the Caronte viaduct (prior to 1940).

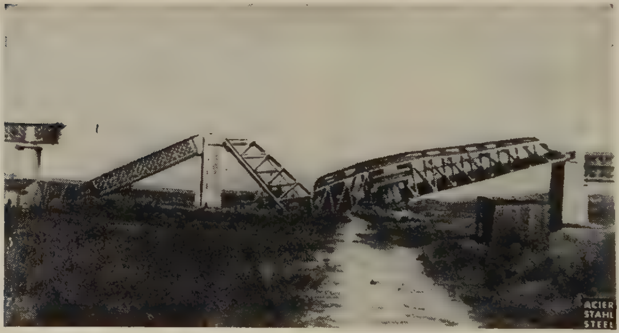

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Fig. 3. — Destruction of the Caronte viaduct in 1944.

The reasons which had led to the original adoption of the swing span were even more potent as far as the recent reconstruction of the bridge is concerned.

The Berre lagoon has now been classified as a major sea port for which, according to the latest international rules, a clearance of 70 m (230 ft.) is required.

The construction of a lifting span, in spite of all the advantages offered by this type of structure, would in any case have met with difficulties as it would have called for important and delicate enlargements of the foundations of the pier on the Martigues side and of the central supporting tower of the old bridge which had been founded on compressed air caissons and were still in such a condition that they could be used. Also, the construction of guiding pylons of over 80 m (262 ft.) height would have been a difficult proposition.

The disadvantages of drawbridge type structures were similarly aggravated by the existing conditions of access.

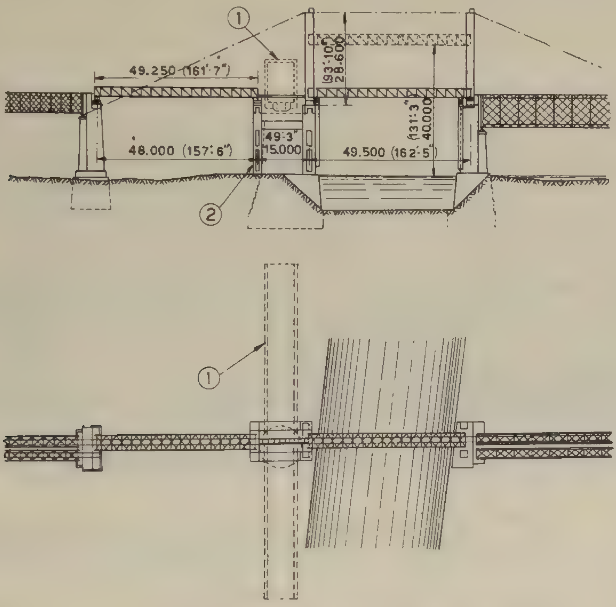

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Fig. 4. — General arrangement of the temporary bridge.
1. New span under construction. — 2. Reinforced concrete platform.

It was therefore decided again to adopt the solution of a swing bridge with general characteristics similar to those of the old bridge.

### Details of the temporary bridge.

It was thus necessary for the temporary bridge to meet the following conditions :

1) to include a movable span of about 50 m (164 ft.) length, crossing the ship canal;

2) to permit the reconstruction of the central supporting tower on the still intact foundations of the old bridge, it being necessary for the supports of the temporary bridge to keep clear of the tower yet to make the greatest possible use of its foundations in order to avoid the need for major pile driving operations;

3) to be so designed that the erection of the permanent bridge was not impeded;

this erection was obviously to be carried out in the direction parallel to the canal. Moreover, it was necessary for the temporary installations to permit the free running of trains over as long a period as possible. On the other hand, it was possible to be content with a single-track bridge.

In the circumstances, the temporary bridge (fig. 4) was constructed as a lifting span which, when lowered, gave a clearance above water level of 23 m (75′ 6″) and when raised, gave a clearance of 40 m (131′ 3″) which was temporarily accepted by the waterways authorities.

This span was constructed with the aid of a Krupp MZ type bridge of 49.50 m (162′ 5″) length which was placed at the disposal of the French National Railways by the French military authorities. This bridge was a through bridge of the N-shaped lattice type, made of high-tensile steel, and was perfectly suited for the purpose as it was light and did not offer much scope for the attack of the wind. It was supported, at either end, by the bottom transom of a steel frame kept clear of the train clearance gauge. The frame itself was suspended on cables which were connected with counterweights running on rails along the steel pylons of 28.60 m (93′ 10″) height which had the dual function of serving as guides and supports during the movements. The lifting operation was carried out by means of an hydraulic device with hinged strut, acting on a trimmer located in front of each of the frames.

On the *Martigues side,* the pylons were resting on the abutment, suitably modified for this purpose. In order to resist the wind forces, it was necessary to provide heavy anchors at the base of the abutment itself.

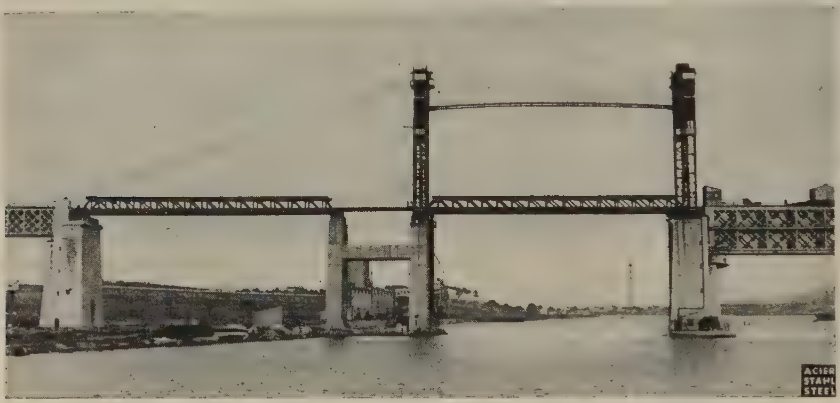

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Fig. 5. — General view of the temporary bridge.

On the *Port-de-Bouc side,* the pylons rested on a reinforced concrete platform, the four pillars of which, measuring 3.60 × 3.00 m (11′ 10″ × 9′ 10″), were clear of a circle of 13.00 m (42′ 8″) diameter corresponding to the dimensions of the central tower to be constructed later for the permanent bridge. The pillars of the platform were founded partly on the set-offs of the masonry of the old foundations, and partly on reinforced concrete piles. Near the top, the pillars were braced by cross-beams of 2.50 m (8′ 2″) height.

The reinforced concrete platform was

bridged by a small auxiliary steel bridge of 14.80 m (48′ 7″) span, carrying the railway track. The height of this structure was reduced so as to permit the construction, below it, of the bottom members of the permanent bridge and of the major part of the steelwork destined to transmit the loads to the tower.

Finally, a second MZ type bridge, 48 m (157′ 6″) in length, was used as a fixed span to carry the track between the reinforced concrete platform and the pier on the Port-de-Bouc side.

The work of constructing the temporary bridge was taken in hand in September, 1945, and completed in July, 1946, by « Entreprise Fives-Lille » with the assistance of the military authorities as far as the installations of the military bridges was concerned, while « Entreprise Schneider » was responsible for the lifting and repair of the approach span of 51.20 m (168 ft.) length which had collapsed.

The work thus constituted (fig. 5) has been in operation without incidents until it was removed, in October 1954, to make way for the new swing span.

**Details of the new swing span.**

a) *General arrangement* (fig. 6.).

The general appearance of the old swing span has been preserved. The main girders, 114.20 m (374′ 8″) in overall length, divided into two equal sections, are of the N-shaped lattice type. Their height varies from 7.60 m (24′ 11″) to 13.90 m (45′ 7″).

As before, they rest at the centres on a tower with exterior stone facing, which has a diameter of approximately 13 m (42′ 8″) and a height of 18 m (59 ft.).

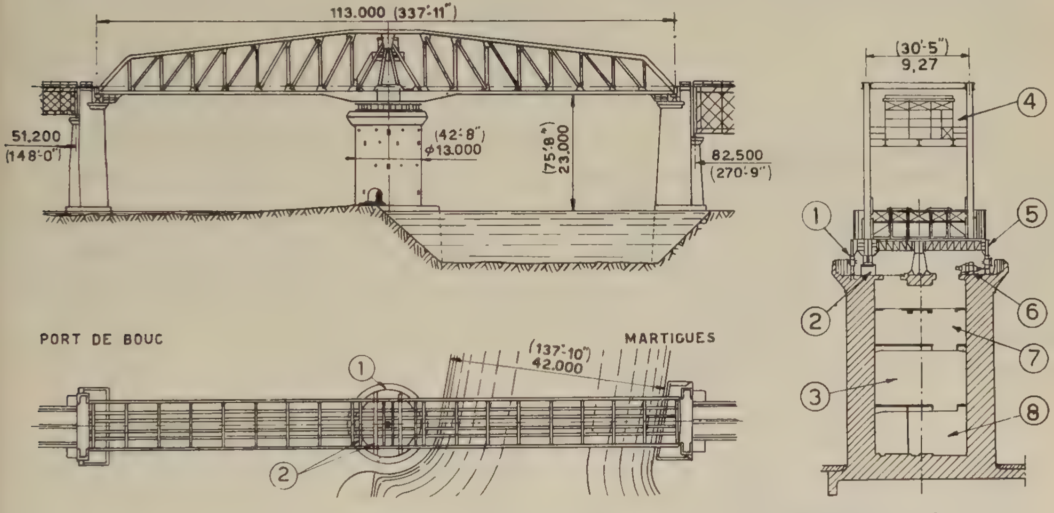

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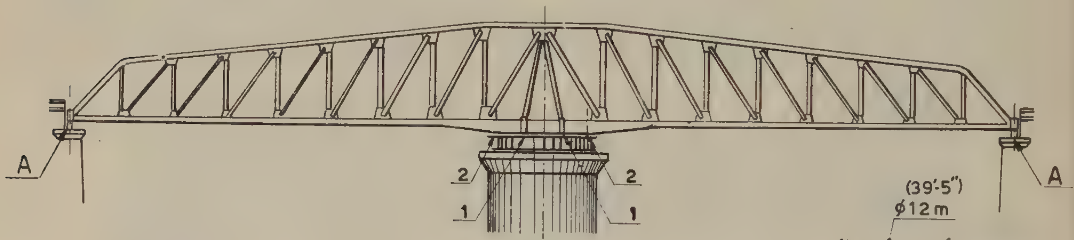
Fig. 6. — Elevation, plan and cross-section of the new bridge.

*Left :* 1. Drum girder. — 2. Steel framework to ensure load distribution. — *Right :* 1. Rollers. — 2. Jacks. — 3. Motor room. — 4. Control cabin. — 5. Drum girder. — 6. Driving motor. — 7. Stores room. — 8. Transformer station.

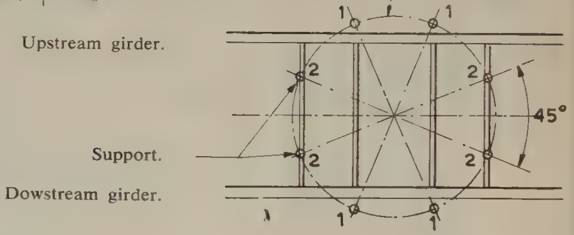
However, the design of the structure differs a good deal from that of the old bridge because of the alterations made in principle to the method of operation. In fact, one of the essential conditions for the reconstruction was to *minimize the time taken for the swing span to open and close,* in view of the expected increase in the number of ships passing through (several openings per *day* instead of a dozen or so openings per *year*).

Therefore, whilst the old span, when serving as a bridge, used to rest on supports arranged in the centre lines of the lateral girders and, when revolving, on a pivot in the centre of the tower, the new span *is supported, during the rotation as well as in the service position, by a ring of rollers* which transmit the loads to the walls of the tower.



**Support reactions :**

| | $R_A$ | $R_2$ | $R_1$ |
|---|---|---|---|
| Bridge closed :<br>maximum ...<br>minimum .... | <br>362,5 t<br>7 t | <br>711,6 t<br>61,6 t | <br>197 t<br>37,1 t |
| Bridge open... | 0 | 225,2 t | 57,1 t |



Influence lines.

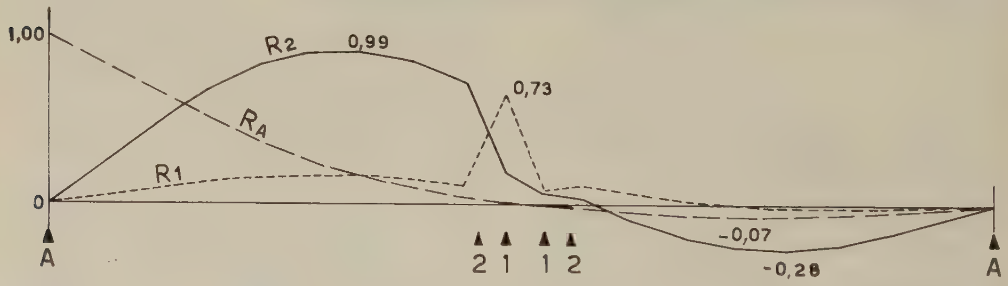


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Fig. 7. — Support reactions of the swing bridge.

The chocking and unchocking operations on the piers are thus eliminated.

Moreover, the new tower is completely hollow, and the space thus gained has been utilized to house the bulk of the mechanism. The latter is electrically operated, and a high degree of automation has been applied in order to eliminate any waste of time during the operation, and to facilitate operation.

Furthermore, as the only voids of the old tower were those of the staircase and petrol tank, the weight of the new tower bearing on the foundations is correspondingly smaller.

b) *Steel structure.*

The main girders carry the two railway tracks through the medium of cross girders spaced at intervals of 6.10 m (20 ft.), and four lines of longitudinal members, one below each rail.

Wind loading is tranferred to the supports by two K-shaped longitudinal wind girders, situated at the level of the upper and lower chords, and associated with a transverse wind bracing which ensures the rigidity of each of the section located at the points of the cross-girders.

A steel floor, 8 mm ($^5/_{16}$") thick, is riveted to the cross-girders and longitudinal members and adds to the horizontal rigidity of the structure, which is of permanent importance. The floor has trap doors at the ends and in the centre to give access to the machinery.

In order to transmit the loads on the roller ring comprised between two roller tracks, the central part of the swing span is designed as an interlaced steel framework resting on eight regularly spaced points of a circular drum type girder which forms one piece with the upper roller track.

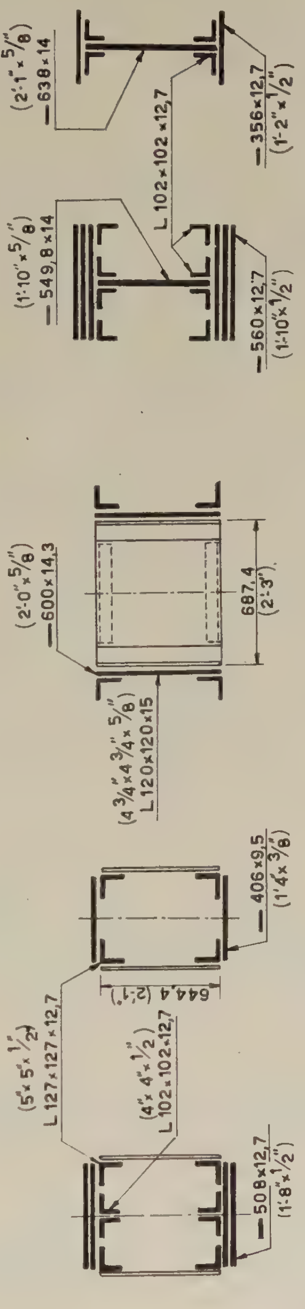
This steel framework consists of :

*a*) two cross-girders, 2.50 m (8′ 2″) in height, spaced out at an interval of 4.592 m (15′ 1″), situated on either side of the centre line of the structure, and having their supporting points on the drum girder *outside* the main girders;

*b*) two further cross-girders, situated at a distance of 3.247 m (10′ 8″) from each of the first-named cross-girders and being of the same height, with their supporting points *inside* the main girders;

*c*) four lines of longitudinal members carrying the tracks, but so designed as to constitute an effective bracing of the cross-girders mentioned above which carry heavy loads.

With this design, the main girders of the new swing bridge constitute a continuous system with five very unequal



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Uprights.

Upper and lower chords.

Diagonals.

Fig. 8. — Structural details.

spans of 50.957 m, 3.247 m, 4.592 m, 3.247 m and 50.957 m (167′2″, 10′ 8″, 15′ 1″, 10′ 8″ and 167′ 2″) with three central supports elastic, instead of the simple system of two continuous spans of 56.50 m (185′ 4″) which was a feature of the old bridge.

The calculation of these girders did not give rise to any particular difficulties. The determination of the influence line of the different support reactions can be reduced to simple calculations of the deformation of the lattice system of the girders, taking into consideration the deformation of the supports formed by the interlaced steel framework, a deformation which is greatly influenced by the effect of the shear forces.

In determining the dimensions of the girders, it was, in any case, necessary to resort to a trial and error method in order to ensure that there is always an adequate predominance of the positive support reactions, both on the abutments and on the tower, and that there is no hammering under any load or temperature conditions.

This is a difficulty usually encountered with swing bridges turning on rollers, which one has sometimes tried to overcome by providing a partial discontinuity of the girders in the central section (Rock Island and 4th Avenue Swing Bridges in New York).

In the case of the Caronte bridge, it was found sufficient to use special steel for the chords of the girder in order to increase their deformability, and to ensure a minimum positive support reaction of 40 t by means of wedging devices at the ends, as a safeguard against any upward movement.

Trial runs with test trains have confirmed the absence of any upward movement even under the most unfavourable load conditions.

### Composition of steel parts.

The steelwork parts of the swing span proper are wholly riveted.

In principle, the double-web chords have a constant height of 0.600 m (2 ft.). However, the height of the lower chord which, in the central section, is required to transmit important loads, varies over a length of 13.25 m (43′ 6″) on either side of the centre of the tower where it reaches a maximum of 2 m (6′ 7″).

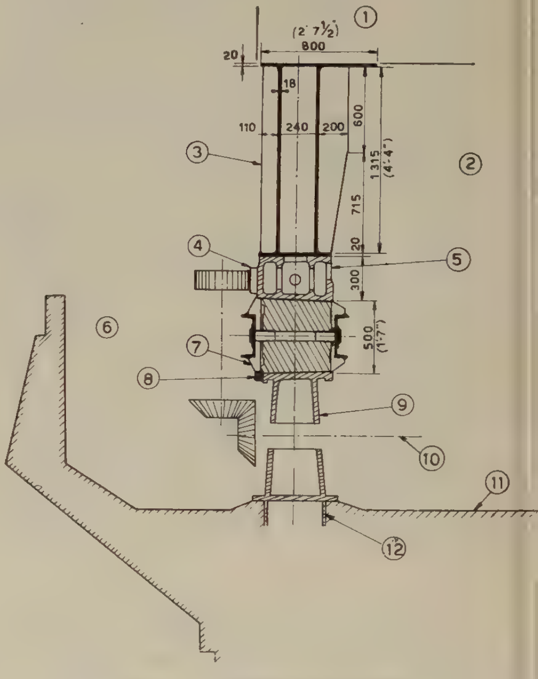

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Fig. 9. — Rotating device.

1. Support girders of the swing span. — 2. Machinery chamber. — 3. Drum girder. — 4. Rack bar. — 5. Unit of the upper roller track. — 6. Inspection path. — 7. Roller. — 8. Outer checking device of the rollers. — 9. Unit of the lower roller track. — 10. Centre line of the transmission for the rotating movement. — 11. Uupper floor of the tower. — 12. Concrete-embedded bedplate.

The vertical and diagonal members, whose sections are shown, in principle, in figure 8, are inserted between the webs of the chords and are riveted to the gusset plates. The vertical members are of the full web type whilst the flanges of the diagonal members are linked by straps.

The simple vertical member at the centre which was a feature of the old bridge but which was now no longer justified, has been replaced by diagonals transmitting the load to points straight above the cross-girders of the interlaced steel framework.

This arrangement proved to be extremely valuable during the construction as it became possible, merely by deferring the mounting of a single diagonal, to assemble the entire bridge as a cantilever structure while trains could pass accross the structure in the course of erection.

The entire steel structure consists of French 42 type steel with the exception of :

1) the chords of the main girders which consist of British HT 548 type steel from stocks held by the French National Railways, and of 55 M type steel with characteristics similar to those of French 54 Ac type steel;

2) the two cross-girders in the centre which, because of their particularly heavy load, are made of 15 D.Fo 65 type steel.

### c) *Tower and turning mechanism.*

As already mentioned, the new span rests on a hollow tower of lightly reinforced concrete, with an exterior facing of Cassis stone, having an external diameter of 12.90 m (42′ 4″) and a wall thickness of 1.20 m (3′ 11″) (fig. 6).

The tower stands on a heavily reinforced concrete slab 2 m (6′ 7″) thick which covers and binds the old foundations which are used again.

The tower has four stories above the ground floor on which the operating gear and machinery are installed.

At the bottom of the tower is the transformer equipment, on the first floor is the power generating set and the distribution switchboard, the second floor serves as stores room, the third contains the pumps, whilst the fourth and last, covering the top of the tower, carries the driving motors and the central pivot of the span.

The floors are solidly integrated with the walls of the tower which they brace, and are made of reinforced concrete. They are connected by a spiral staircase, likewise constructed in reinforced concrete.

The tower carries the swing span through the medium of the turning mechanism which consists of (cf. fig. 9) :

— a steel bedplate embedded in a reinforced concrete sill on the top of the tower which is integrated with the upper floor carrying the machinery of the turning mechanism;

— a lower roller track consisting of cast steel, mounted and adjusted on the concrete-embedded bedplate;

— a ring of 63 tapered steel rollers with a central diameter of 500 mm (1′ 8″), kept at the proper distance and in the proper direction by a cage consisting of two rings of interlaced profiles.

In order to facilitate the installation of the machinery on the upper floor of the tower, the rollers are not orientated on the tower by an array of radial members linking them to the central pivot, but they simply rest, by means of spherical contacts, on an outer ring forming one piece with the lower roller track;

— an upper track fixed by bolts to the bottom of the drum type girders which supports the span through the medium of the interlaced steel framework described above.

The upper roller track carries on the outside, the annular rack bar in which the four operating pinions engage :

— the drum girder, which is a circular box girder with two steel flanges 18 mm (3/4″) in thickness and 1.315 m (4′ 4″) in height, weld-assembled with the top plating which carries the support plates of the interlaced steel framework, and with the bottom plating which forms one piece with the upper roller track.

Numerous steel struts are provided to prevent any buckling of the girder at the point of the considerable concentrated loads (720 t), which it has to carry.

The stiffness of this girder is such as to spread the loads on the rollers as evenly as possible. The stiffness is increased by the effect of the upper roller track, whose cross-section takes part in the resistance, the necessary connections having been provided for this purpose.

The circular girder is perfectly centered on the roller ring and on the tower by means of radial lattice girders through which it is connected to a hub revolving around a central pivot on the top floor of the tower.

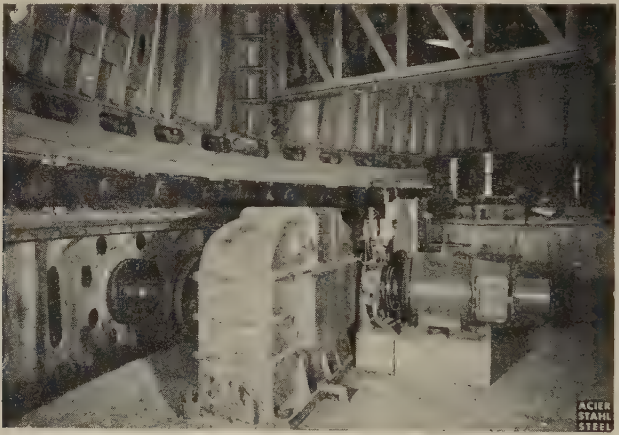

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Fig. 10. — Set of driving motor and reduction gear for the rotating movement of the swing span.

These radial girders serve to support the roof of the machine house which is located on the top floor of the tower, in the same way as the inner flanges of the drum girder, the roller ring and roller tracks form its walls.

Jacks permanently installed in the machine house permit the lifting of the span and of its circular girder so that the rollers can be laid bare.

The inspection of the vital parts from the machine house is therefore very easy. On the outside, a circular inspection path, accessible from the span, surrounds the top of the tower and permits the maintenance of the outdoor machinery and the removal and, if necessary, the replacement of the rollers.

d) *Machinery and electric equipment.*

The machinery operating the swing span comprises the mechanisms for the rotating movement, for the wedging and locking of the span at the piers, and for the fishplating of the tracks where they are connected with those of the fixed spans.

All this machinery has been designed with a view to reducing the operating time to a minimum, and to achieving completely automatic working.

1. *Rotating mechanism.*

As already mentioned, the rotating movement of the swing span is obtained by means of four pinions which act on the rack bar, fitted to the upper roller track.

These pinions are operated by individual driving motors through the medium of reduction gear boxes, installed on the top floor of the tower on the inside of the roller tracks (fig. 10).

The four reduction boxes which are of

a commercial type produced by Citroën, have double helical gearing with an efficiency of 0.97, and are operated by four 25 HP electric motors.

The motors are mounted in pairs arranged diametrically, and normally, only one pair is in operation at a time.

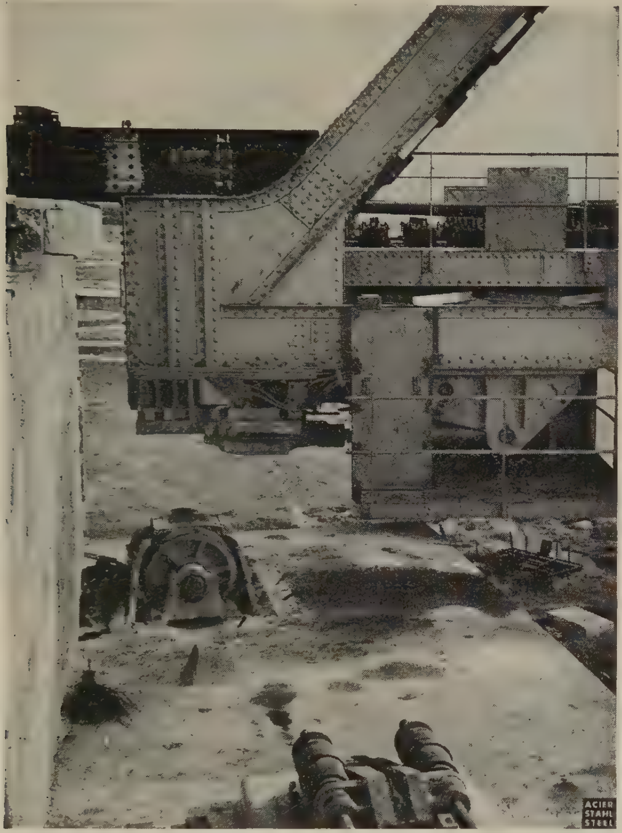

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Fig. 11. — Wedging and locking device on the pier.

In the event of an exceptionally high wind, the four motors can be used in series connection at half speed.

One of the motors of each pair carries a tachometer for the « Rototrol » control of the Ward-Leonard control circuit, which automatically ensures the control, start, acceleration, deceleration and stop of the rotary movement.

The power provided for the rotating movement is thus halved in comparison with the power installed in the old bridge in spite of the fact that the average turning speed has been nearly tripled.

This result is due to the perfection of the mechanism as well as to the adoption of basic assumptions which appeared to be more realistic.

Thus, instead of assuming a maximum

wind pressure of 60 kg/m² exerted on one half of the span, one has now assumed a maximum wind force of 25 kg/m² (70 km/h or 43 ½ m.p.h.) corresponding to the extreme conditions under which navigation along the canal is still possible, with a maximum difference of 4 m (13 ft.) per second between the two ends of the structure.

A system of electro-pneumatic brakes at the motor outlets ensures the immobilisation of the bridge in the open position and in any position in which the bridge is not locked.

If the power supply should fail, the bridge can be swung back by hand by means of hand-operated winches acting on the motor shafts, through chains which are put on when needed for this purpose.

2. *Securing the span on the piers.*

The swing span is secured on the piers partly by being wedged against support blocks embedded in the reinforced concrete of the abutment, and partly by a horizontal locking device which serves to keep the span strictly in its theoretical alignment (fig. 11).

The wedging devices ensure, firstly, the lifting of the cantilevered span by means of suitably shaped slide blocks which move on rollers forming one piece with the support blocks, and secondly, the final wedging by means of wedges and spherical bearing which have the effect of centreing the reactions accurately on the supports, and freeing the rollers. The slides and wedges are operated by dual purpose hydraulic jacks which are mounted on the main girders and act directly in the centre line of the slides.

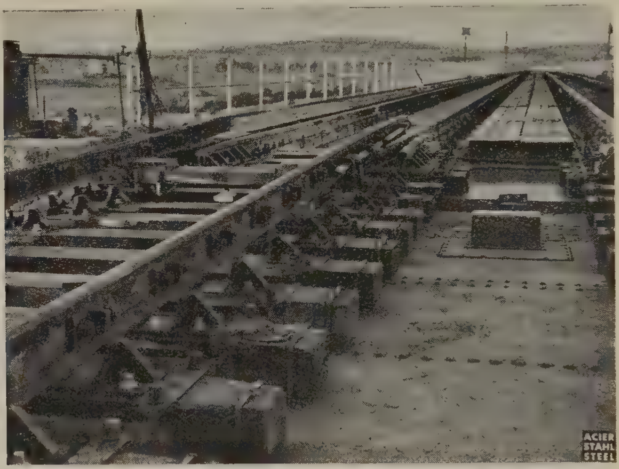

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Fig. 12. — Fish-plating of the track.

The slides are checked mechanically at the end of their travel by checking devices which are retracted during the movement.

Locking is ensured, first of all, by an automatic bolt which holds the span approximately in its correct position, viz. within ±20 mm of its theoretical centre line.

The bolt consists of a vertical finger, fixed in the centre line of the last cross-girder and fitted, at the bottom, with a roller which drops, after passing over inclined guiding planes, into a clasp elastically mounted on the abutment.

The walls of the clasp are fitted with springs which absorb the residual energy of the span and finally ensure its return to the correct alignment.

This first locking process is supplemented by the action of two horizontal bolts which are propelled by hydraulic jacks and slide in guides mounted under the ends of the main girders and engaging in clasps arranged in the water-side walls of each pier.

The wedging devices are so adjusted that they exert a pressure of at least 40 t on the span, thus checking any upward movement under any temperature and load conditions.

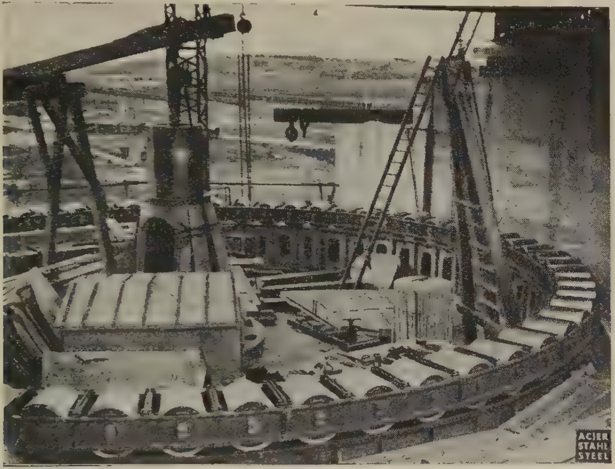
The end of the bolts and the entrance of the clasps are shaped as inclined planes permitting the bolts to engage and the necessary displacements to take place to ensure the correct alignment and, if necessary, trueing of the girders.

The action of the horizontal bolts ensures the correct alignment of the span to within 1 mm.

e) *Fish-plating of the rails.*

The apparatus destined for the fish-plating of the rails is designed on principles similar to those applied to certain swing bridges of the Netherlands Railways.

This fish-plating device consists of a kind of expansion joint where the wing rail can be raised vertically by 0.20 m (8″) so as to provide clearance for the rotation. The fixed point is situated 11.20 m (36′ 9″) away on the bridge deck (fig. 12).



*ACIER-STAHL-STEEL block.*
Fig. 13. — Ring of rollers.

When the swing bridge has come to a standstill, the movable rail is lowered into special stools which interlock transversely, and in which the rail is blocked by a supplementary locking device. The perfect continuity of the track is thus ensured, and the end joints do not call for any speed restriction whilst, under the former arrangements, a speed limit of 20 km/h (12 m.p.h.) had been necessary.

Power for the operation of the different mechanisms is taken from the mains supply at 15 000 V and transformed by two transformers, viz. one of 100 kVA for the rotating movement, and one of 16 kVA for the ancillary apparatus.

The 100 kVA transformer feeds the asynchronous 100 HP motor of a Leonard converter set with automatic speed regulation for any load, by means of « Rototrol » equipment supplied by the Schneider-Westinghouse Company.

Emergency current supply is ensured by a Poyaud Diesel engine with identical electrical characteristics.

Overall control is concentrated in a control cabin located above the tracks where there is an equally good view of the railway and the shipping canal.

In principle, the control is automatic in either direction of rotation. For safety reasons, however, the bridge should move aside away from the oncoming ship. Normally, therefore, all that the operator has to do is to press a button when the controls have been released by key transmitter, the authorization for the operation being given by Martigues station.

If necessary, however, he still has the possibility of operating the bridge by individual electric control of each operation.

Moreover, these operations can also be carried out manually on the spot.

## Construction work.

a) *Erection of the swing span.*

The swing span has been constructed in such a way as to minimise the interruptions to railway traffic as well as shipping.

For this purpose, the two wings of the new span were erected symmetrically in cantilever fashion, in the « bridge open » position, beginning at the central tower which had previously been reconstructed on the foundations of the old structure.

The first requirement was to consolidate these foundations by major repairs and cement injections as they showed cracks and signs of decomposition due to sea water action. Their protection was supplemented by a curtain of steel sheet piling, driven on the side of the canal and integrated with the reinforced concrete enclosure.

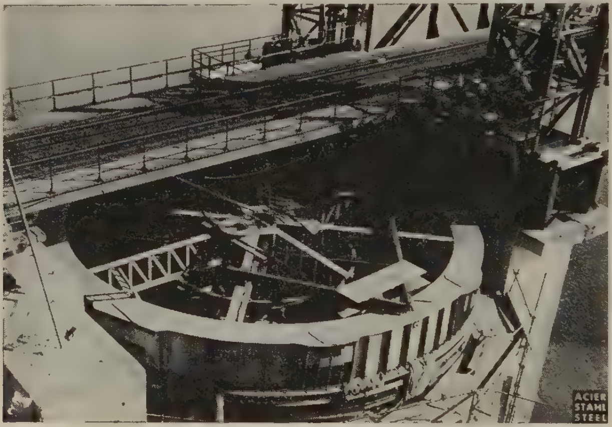


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Fig. 14. — Erection of the drum girder.

The most delicate part of the work, consisting in the construction of the concrete-embedded bedplates and the adjustment of the lower roller track, was then carried out in the narrow space comprised between the auxiliary bridge deck of 14.80 m (48′ 7″) and the top of the tower.

Due to the very special but necessary

care taken, it was possible to fix the lower roller track, previously aligned to a tolerance of 1/100 mm on the 13 m (42′ 8″) diameter tower at the Schneider-Creusot works, on the concrete-embedded bedplate and to adjust it both vertically and horizontally to a tolerance of between 2/10 and 3/10 mm.

The rollers and the circular girder, focussed on the central pivot, were then installed and carefully weather-protected (fig. 13 and 14). It was then possible to carry out the erection of the members of the interlaced steel framework and the lower chords of the central section of the main steel structure.

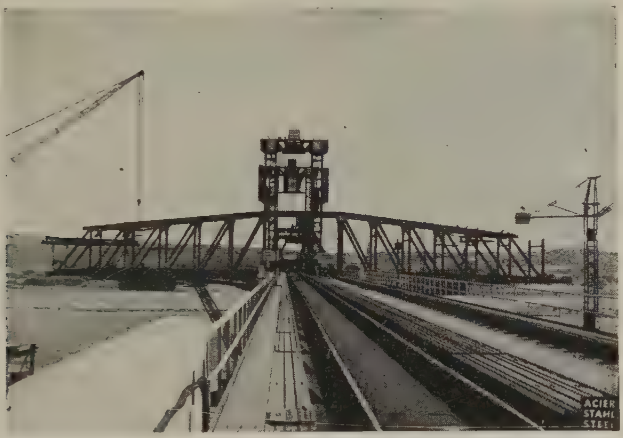

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Fig. 15. — View of the swing span during the erection. The photograph shows where the diagonal at the centre is still missing.

In order to avoid any deterioration at the roller ring or its tracks, the span was mounted on an auxiliary framework, resting on the top floor of the tower and fitted with jacks which permitted, at any time, the adjustment of the level of the span. Provision was also made for a special checking device preventing an accidental rotation under the impact of non-symmetrically attacking wind forces, a contingency that had in fact occurred during the erection, on falsework, of the swing span constructed in 1914. Moreover, special safety struts were provided outside the tower, just below the vertical member of the third panel, in order to support the vertical loads arising from a momentary lack of balance of the two wings, and in order to obtain a further safeguard against accidental rotation.

The erection of the steel framework and lower chords of the main steel structure did not give rise to any special difficulties other than those due to the narrowness of the working site. It may merely be mentioned that the longitudinal members and cross-girders situated at the auxiliary bridge deck of 14.80 m (48′ 7″) had to be given a longitudinal joint so that the mounting of their top parts could be deferred until the auxiliary deck could be finally removed.

The erection of the girders proper was commenced by erecting temporary columns in the centre of the span, which were carefully wind-braced in order to safeguard against any possible transverse deformation. These columns were provisionally fixed on the central top gusset plate for the diagonals, and removed when the work was completed. It was thus possible to mount the entire steel structure on the tower, rigidly and completely riveted with the exception of the lower part of a single diagonal which left the way clear for trains to pass across the swing bridge (fig. 15). When the steel structure had been finally placed on the circular girder, the latter was raised in order to relieve the roller ring of any load during the erection work.

The unimpeded operation of the temporary lifting span for the purpose of enabling ships to pass was likewise ensured (fig. 17).

The erection of the overhung wings did not give rise to any particular difficulties apart from the very great care that had to be taken to ensure the perfect vertical adjustment of the span in the transverse as well as in the longitudinal direction.

It was in fact desirable that the levels were such that, on the occasion of the first turning operation (there being no possibility of adjustment on the pier), the lifting of the span on any of the two piers in the horizontal position should introduce the minimum reaction of 40 t under each girder, assuming the deck to have uniform temperature.

It was possible to achieve this result by giving the girder a suitable camber and by arranging the erection work accordingly.

The calculations of the deformation, based on the normal modulus of elasticity of steel (20 000 kg/mm$^2$) resulted in a theoretical sag of 125 mm at the end of each wing.

The complete neutralisation of this sag by the wedging devices would have introduced a minimum reaction of 83 tonnes which was liable to be increased further whenever the upper chord had a higher temperature than the lower chord (1.5 t extra load for each degree Centigrade of difference in temperature). In spite of the safety coefficients adopted in the calculation of the machinery, the wedging forces would have become unduly great.

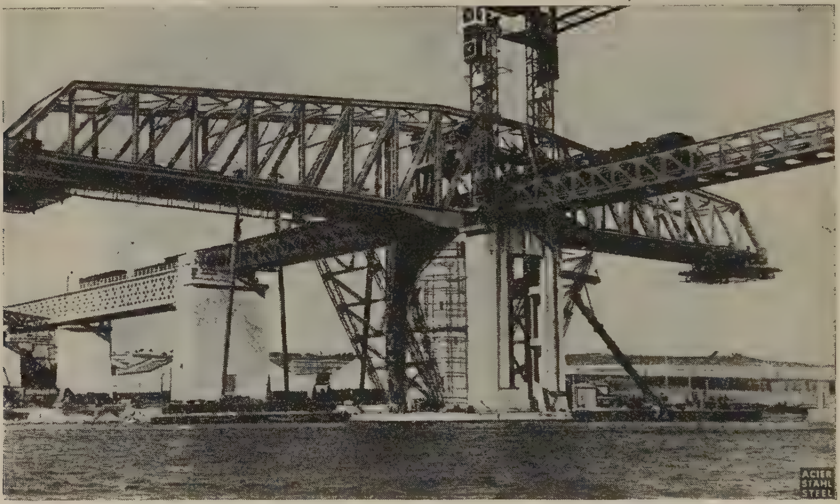

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Fig. 16. — Rail traffic passing through the structure during the construction work.

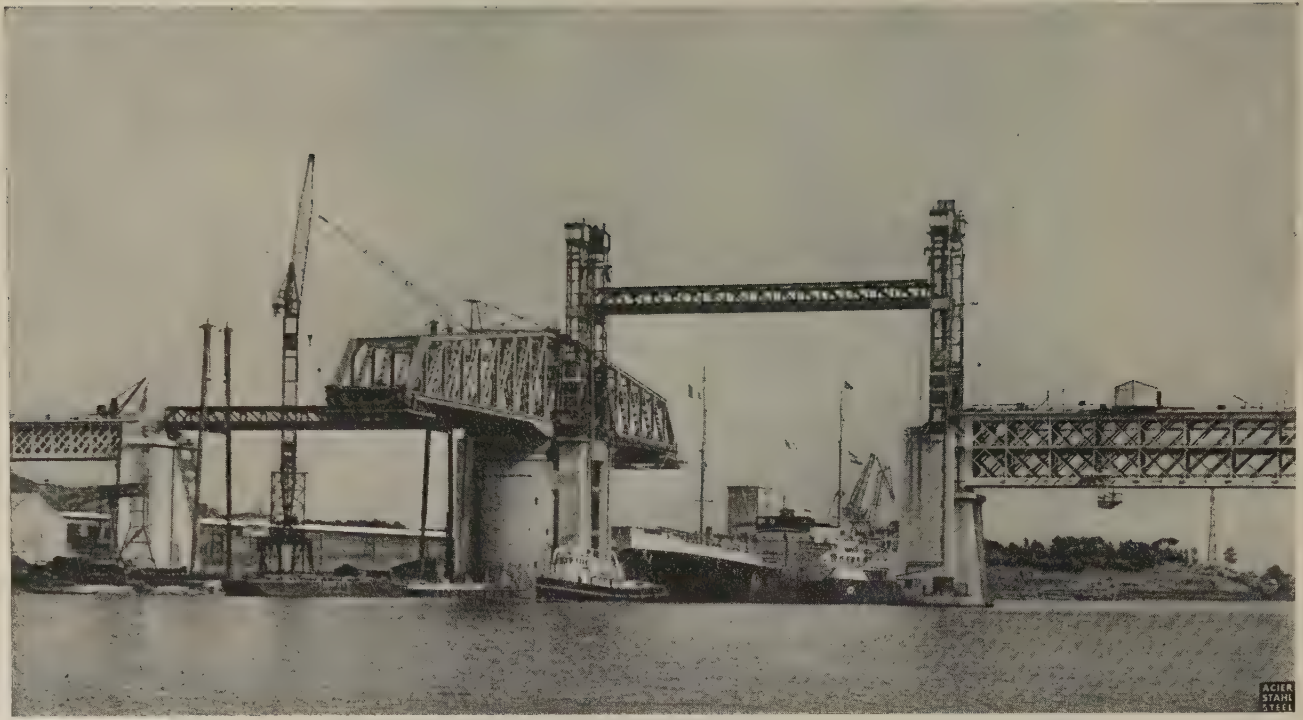

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Fig. 17. — Shipping passing below the bridge during the construction of the swing span.

It was therefore necessary to confine the lifting movement to $\frac{40}{83} \times 125 = 60$ mm. In other words, it was advisable to give the girder a camber of 125 — 60 = 65 mm at the end.

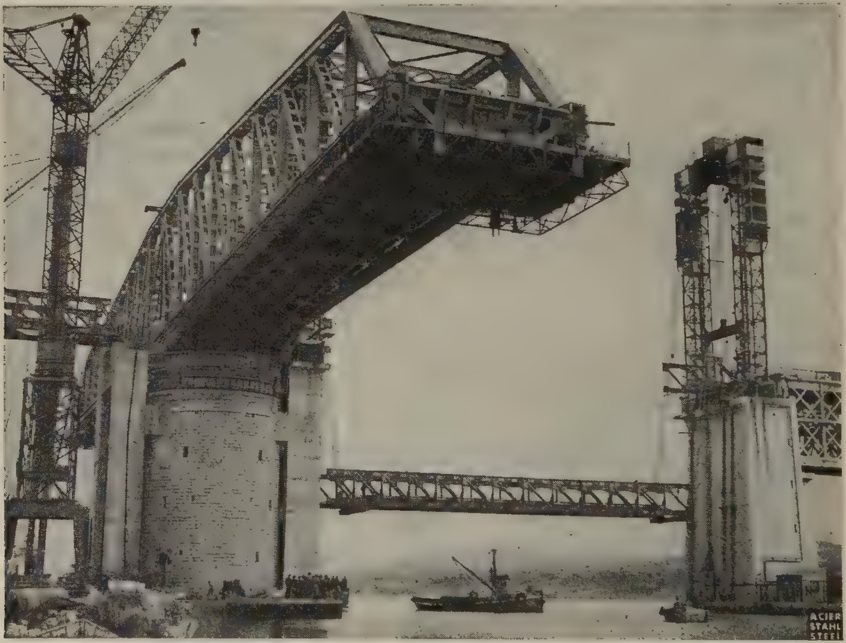

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Fig. 18. — Removal of the lifting span.

In practice, there was a risk of this calculation being inaccurate as the actual *sags* of the bridge are generally smaller than the theoretical sags due to the influence of the accessory parts (wind bracing, bridge floor, etc.), which increase the stiffness of the structure. It was therefore necessary to introduce an experimental factor. The factor used in this connection was the one experienced at the old bridge (about 75 %), and the true sag of the bridge has thus been assumed to become approximately $125 \times \frac{3}{4} = 93$ mm.

The lifting movement causing the reaction of 40 t was thus calculated to be $\frac{40}{83} \times 93 = 45$ mm, and the camber 48 mm.

The camber finally adopted was 45 mm. In the event, the total sag after the erection was found to be 54 mm instead of 48 mm, and the lifting movement corresponding to the reaction of 40 t as controlled at the jacks was found to be 37 mm.

This difference is due to the fact that conditions necessarily vary as between one construction job and another. On the other hand, the lifting movement for the reaction of 40 t shows that the structure is more rigid than the old one, the reaction coefficient of the actual sags in relation to the calculated sags being 65 % instead of 75 %.

b) *Removal of the temporary installations. Inauguration of the swing span.*

On 4th October, 1954, on the date already determined nearly two years beforehand, railway traffic over the bridge was interrupted and the removal of the temporary installations began.

These operations, planned in detail so as not to take longer than 12 days and not to interrupt shipping for more than 7 days, did not give rise to any special difficulties other than those arising from the coordination of all the operations to be prepared or to be carried out in a narrow space, 25 m (82 ft.) above water level.

The hydraulic jacks, walkways, and the auxiliary bridge deck of 14.80 m (48′ 7″) were removed immediately by means of tackles and taken away partly by water, partly by rail.

The fixed span and lifting span weighing about 160 t were lowered to the ground or on a barge after their ends had been loosened and held by tackles in their service position (fig. 18).

The portals and counterweights were cut off by means of a blow pipe and removed in separate parts with the aid of two Weitz cranes which had been used for the erection of the swing span, and with the aid of a third crane erected on the approach to the viaduct on the l'Estaque side and brought forward to the fixed span of 82.50 m (270′ 2″) when traffic had been interrupted.

During this time, the missing parts of

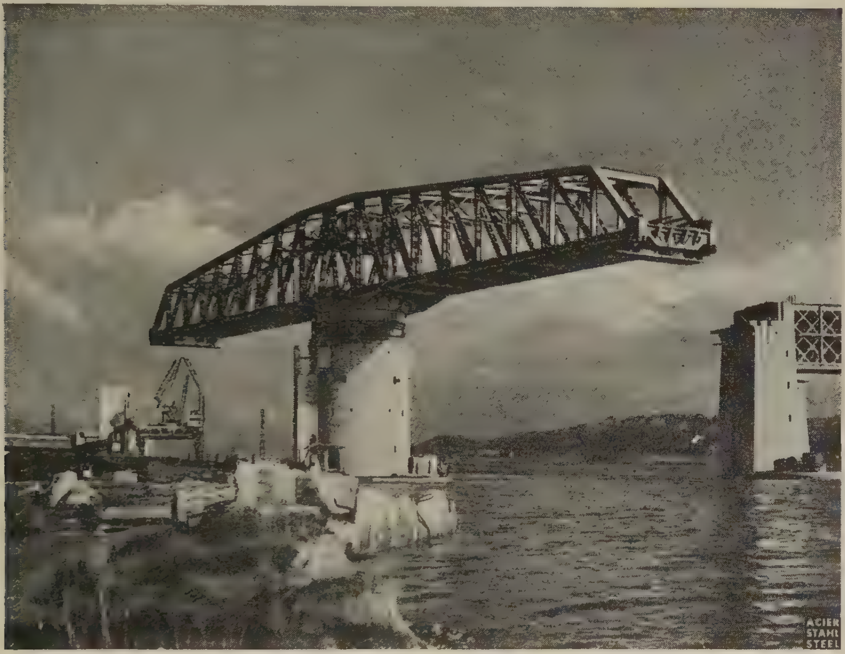

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Fig. 19. — First rotation of the completed swing span.

the central section of the span were mounted, and the temporary columns and bracings removed.

When the supports on the piers were cleared, the most delicate part of the final operations was carried out : the removal of the concrete support blocks of the temporary spans, the installation and adjustment of the locking and wedging devices for the swing span, and the erection and preparation of the electric machines and controls. It was possible to carry out the first rotation of the swing span only 16 days after the date on which railway traffic had been interrupted. The swing span was taken into regular operation after 65 days on 9th December 1954, after the prescribed tests had taken place.

The behaviour of the span during the passage of trains has been very satisfactory. No movements were observed at the supports, and trains have been able to pass the fish-plated end joints at speeds of 100 km/h (62 m.p.h.) without the slightest incident.

The sags under live load have not exceeded 22 mm (7/8″), compared with the calculated value of 32 mm (1 1/4″).

It is, incidentally, intended to supplement the deformation measurements by strain measurements in order to verify the accuracy of the calculations made for the swing span and the circular girder.

Since the span was taken into operation, it has worked with automatic control without any incident. Some improvements in detail have still been made with a view to bringing the actual working diagrams closer to the theoretical working diagrams.

The demolition of the temporary platform of reinforced concrete has progressed with the result that the new bridge has gradually assumed the elegant appearance of the old one, perhaps enhanced by the modern conception of the structure (fig. 19).

The construction of the new swing span necessitated, in all, the use of 1.200 t of steel and 300 t of mechanism, a weight virtually the same as that of the old span in spite of the appreciable increase in the live loads for which the new structure had to be calculated. In addition, 1 200 m$^3$ of reinforced concrete were required for the reconstruction of the central tower above the water level.

The work had been entrusted to the « Société des Forges et Ateliers du Creusot (Schneider) » which had constructed the original swing span. The civil engineering work was sub-contracted to the « Enreprise Joya-Chabert ». The other work was shared out among the specialized workshops of the principal contractors and their subsidiary companies :

— the « Ateliers du Creusot » were responsible for the mechanical parts;

— the « Chantiers de Chalon-sur-Saône » manufactured and erected the steel structure;

— the electrical parts were entrusted to the « Société Le Matériel Electrique S. W. ».

The design studies were in the hands of the appropriate technical departments of the French National Railways, and the supervision of the actual work on the site was entrusted to the Mediterranean Region.

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# OFFICIAL INFORMATION

ISSUED BY THE

# PERMANENT COMMISSION

OF THE

# International Railway Congress Association.

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## Meeting of the Permanent Commission, held on the 1st December 1956.

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The Permanent Commission of the International Railway Congress Association held a meeting on the 1st December 1956, at 3 p.m., in the Belgian National Railways Headquarters Offices, in Brussels.

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Mr. De Vos, *President*, opening the meeting adressed a warm welcome to the personalities present. He then requested the Assembly to approve the Minutes of the last Meeting held on the 4th June 1956 in The Hague.

Mr. Ghilain, *General Secretary*, informed the Meeting of the designation of Mr. Ivan Andreevitch Ivanov, Graduate of Technical Sciences and Director of the Scientific Institute of the U.S.S.R. Railways, to occupy the seat of member on the Permanent Commission attributed to the Union of Socialist Soviet Republics.

The Assembly ratified this nomination˙

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Mr. Ghilain, *General Secretary*, reported to the Assembly on the progress of the preparatory works relative to the 1958 Madrid Congress. He gave the names of the reporters designated for the drafting of the reports on the ten questions on the agenda of this Session (*).

Mr. Ghilain added that, at the present time, the questionnaires relative to the first nine questions have been drafted and two questionnaires have already been sent out to the affiliated railway administrations.

In view of the Madrid Congress, the functions of *Presidents of Section* will be assumed by the following personalities :

### SECTION I. — **Ways and works.**

Mr. F.P. Villamil, Directeur Adjoint du Réseau National des Chemins de fer Espagnols (RENFE);

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(*) The text of the questions of the next Madrid Congress was published in our *Bulletin* for October, 1956. The list of these questions together with the names of the reporters will appear in one of the next issues of our *Bulletin*.

### SECTION II. — **Locomotives and rolling stock.**

Mr. J. RATTER, C.B.E., Technical Adviser to the British Transport Commission;

### SECTION III. — **Working.**

Mr. SOULARD, Directeur du Mouvement à la Société Nationale des Chemins de fer français;

### SECTION IV. — **General.**

Dr. H. GSCHWIND, Président de la Direction Générale des Chemins de Fer Fédéraux Suisses;

### SECTION V. — **Light railways and colonial railways.**

The holder will be designated in the near future by the Ministry of Transport (Italy).

***

Mr. J. DE AGUINAGA, *General Manager of Railways, Tramways and Road Transport, at the Ministry of Public Works, Spain*, reported to the Meeting, at the President's request, on the arrangements already taken by the Spanish Authorities.

The Local Organizing Commission has been constituted and includes the leading personalities of the transport and communications field.

The Congress will be held in the spacious premises of the « Cité Universitaire » at Madrid, during the last ten days of September 1958. Mr. DE AGUINAGA assured the Assembly of the unanimous will of the Spanish Authorities to do all they can to make this Congress a success at least equal to that of the Madrid Congress of 1930. He supplied particulars on the hotel accommodations in the Spanish capital and promised the best welcome to the delegates to this Session.

The PRESIDENT, on behalf of the Meeting, expressed his thanks to Mr. DE AGUINAGA and asked him to convey same to the Spanish Government.

***

The provisional accounts (up to the 7th November 1956) of the receipts and expenditures were approved as well as the proposed budget for the financial year 1957.

The General Secretary then reported on the favourable financial situation of the Association and stated that it was suggested, while maintaining the rate of 0.28 Gold-franc per kilometre, fixed by the Permanent Commission in 1954, for the contribution to make a call for the year 1957 for an amount of only 0.14 Gold-franc, i.e. half of the fixed rate. This reduced rate would be, under normal conditions, considered also for the year 1958.

— These proposals were unanimously approved.

***

Mr. GHILAIN mentioned that no resignations were recorded in 1956. On the other hand, the affiliation of the *U.S.S.R. Railways* has resulted in an increase of 120 700 kilometres (approx. 75 000 miles) of the mileage.

The International Railway Congress

Association includes at present 34 Governments, 10 Organizations and 101 Railway Administrations with a total mileage of 591 024 kilometres (approx. 367 230 miles).

Moreover, the *Panamerican Railway Association* has made a request for affiliation to our Association as adherent organization. This request was approved.

***

The Meeting ended after the examination of various items concerning the activities of the Association since the last session of the Permanent Commission, in particular in connection with the « Bulletin Sales » and « Advertising » Departments.

*The General Secretary,* *The President,*
(s.) P. GHILAIN. (s.) M. DE VOS.

M. WEISSENBRUCH & Co. Ltd.
Printer to the King

(Manag. Dir.: P. de Weissenbruch,
238, chaussée de Vleurgat, XL)

Edit. responsible : P. Ghilain

PRINTED IN BELGIUM